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A PRACTICAL TREATISE

ON

ELECTRO-DIAGNOSIS.

A PRACTICAL TREATISE

ON

ELECTRO-DIAGNOSIS

IN

DISEASES OF THE NERVOUS SYSTEM

BY

A. HUGHES BENNETT, M.D.
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PREFACE.

The employment of electricity as a method of physical diagnosis in diseases of the nervous system is now recognised by neurologists as an important aid in their investigation. As information on the subject is more widely extended, this fact is being impressed upon the profession in general.

It has frequently been pointed out to the author, by students and others, that we do not possess in the English language any practical systematic work devoted to this subject. In the following pages an attempt is made to supply this want.

The task has been by no means an easy one. Our knowledge of the whole question is imperfect, its literature is limited, and its doctrines are uncertain and conflicting in their testimony. This treatise professes to supply in a condensed form all that is definitely known of the subject up to the present time.

Without claiming to contain new discoveries the contents of this book are so far original, that all the facts therein advanced have been verified personally by the author, and all the cases detailed, have with one exception, been observed and reported by himself. Of these the large majority have been under his own treatment, and as regards the exceptional few he is indebted to his colleagues and friends for permission to place them on record.

The cases reported are not intended in every instance to be a complete clinical record. Such particulars are only given as serve to establish the diagnosis.

This treatise is, therefore, only what it professes to be, the systematised experience of a practical worker, and aims at conveying to its readers the means of utilising at the bedside a physical agent of great value, in the investigation of an obscure class of diseases.

The author has to acknowledge the kind help of Mr. Charles Hebbert for his assistance at many of the clinical observations, and for the revision of the proof sheets of this volume.

A. H. B.

London.
July, 1882.

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A PRACTICAL TREATISE ON ELECTRO-DIAGNOSIS IN DISEASES OF THE NERVOUS SYSTEM.

CHAPTER I.

INTRODUCTION—ELECTRICITY AS A PHYSICAL AGENT IN THE DIAGNOSIS OF DISEASES OF THE NERVOUS SYSTEM.

THE advances which medicine has made during the last generation as a practical and scientific art, is in great part the result of the application of physical agents to the purposes of diagnosis. From the earliest period of its history to comparatively recent times, the accurate appreciation of disease in the living subject has been in the highest degree unsatisfactory, depending as it did upon the vague and uncertain statements of the patient, and the symptoms observed during life by the unaided senses of the physician, hence the comparative uselessness of the vast number of accumulated observations and opinions recorded during many centuries. As general knowledge advanced and the members of our profession received a more liberal and universal education, physics in its various branches has been taken advantage of as a means of assisting and supplementing our powers in the investigation of morbid states. Acoustics, optics, mechanics, and chemistry, more especially, have up to the present, chiefly lent their valuable aid in this direction, and as our learning further advances doubtless other branches of physics will be enlisted for the same object. It is unnecessary to advocate the importance of the stethoscope, the ophthalmoscope, the laryngoscope, the microscope, the speculum, the thermometer, and many other such instruments employed for the purpose of exact precision and research. Besides revealing to us conditions which without their aid would be unknown, they give us the means of establishing, demonstrating, and recording, healthy and diseased states in a manner at which our forefathers could only surmise, thus raising medicine from a calling of mere speculation and hypothesis, to as near an approach to an exact science as a study of living beings can attain. In this way the diagnosis of many diseases formerly impossible or uncertain is by these physical means now reduced to a certainty. Affections of the eye, the throat, and other cavities of the body can be thoroughly explored, and their condition displayed, the state of the organs in the chest, the existence of fever, and a variety of other morbid states can be demonstrated with an accuracy and recorded with a precision which a century ago would have been impossible. This improved diagnosis must necessarily in turn have a beneficial effect, on what after all is the final aim of our art, namely the successful treatment of disease, as a rational knowledge of the nature of the morbid state, must always preceed the intelligent attempt at its cure.

A large and important class of diseases, namely those of the nervous system, have more especially baffled our attempts in this direction, and when we consider what complicated and delicate structures are here involved, our comparative ignorance of even their healthy functions, and our still greater want of knowledge of their conditions in disease, any agent which can throw light on these difficult problems, cannot fail to prove of immense practical service. In comparatively recent times electricity in its different forms has been utilised for this purpose, and although at present our knowledge of all its advantages is as yet imperfect, there are already enough facts to indicate the great practical importance of the subject, and to point to a vast field of research, which will doubtless lead to future profit. In the arts, electricity, as a physical agent, has taken a place, probably second to none, in contributing to the comfort and convenience of mankind, and daily do we see introduced new applications of its marvellous powers, employed in useful directions. In medicine its position hitherto has not been so firmly established amongst the mass of the profession, as possibly its importance deserves. It is not my purpose to enter into all the causes of this neglect, beyond suggesting that doubtless the expense, complication, and labour hitherto connected with the apparatus, combined with a want of knowledge of its properties, has in great measure rendered its use inpracticable and unpopular. This feeling has further been fostered by the fact that for a long time, and probably for the reasons stated above, the treatment of disease by electricity has chiefly remained in the hands of specialists, and often in those of unscrupulous persons who have brought discredit upon the agent by utilising it for their own, rather than for scientific or public advancement. A prejudice has thus arisen against electricity generally as applied to medicine, which may take time to eradicate, but if its principles be genuine and its advantages substantial this will soon be effected, and indeed in great part this has already been attained. In these days a physician totally ignorant of the elements of electricity, and their practical applications in paralytic affections, must be looked upon in the same light as that of the older practitioner, who from his inability to use it, refused to admit the utility of the stethoscope, and who in consequence failed to take advantage of the means of diagnosis with which modern discovery provided him. The question of expense, bulk, complication, and knowledge of electrical apparatus and it properties, although by no means yet perfect, is sufficiently so for practical purposes, and the above mentioned prejudices can in no way reasonably apply to its application in diagnosis; no one need therefore excuse himself from entering upon an investigation calculated to facilitate our researches into the nature of so obscure and complicated a class of diseases as those of the nervous system.

The question may now be asked—In what way does electricity assist us in diagnosis? This may be briefly answered thus. It enables us accurately to determine the anatomical conditions of nerve and muscle, as it has been ascertained that these bear a constant relation to the electrical reactions. At first sight this appears a small matter, but on consideration it will be found that the knowledge thus attained is no less important than that derived from the other physical sources we are accustomed to rely upon in the diagnosis of disease. Take the most popular of all these as an example—the stethoscope. This instrument reveals to us certain sounds within the body which are, after all, very limited in number. These by themselves prove little or nothing, but when combined with other methods of research, such as palpation, percussion, etc., they enable us with great exactitude to arrive at the anatomical condition of the organs. This, again, in association with the history, symptoms, and other circumstances of the whole case finally permit us to complete our diagnosis. Precisely in the same way we do not by electricity alone profess to settle all the difficult and complicated problems met with in diseases of the nervous system, but, as with the stethoscope, we determine by its aid certain physical changes in the tissues, the knowledge of which, in conjunction with all the other bearings of the case, materially assists us in arriving at a correct and scientific conclusion. We shall afterwards see that in health the various currents produce well marked and definite phenomena when applied to nerve and muscle, and so constant are these that fixed laws can be deduced for our guidance. We shall also find that in disease these conditions are in proportion altered. It is the careful consideration of the relations which exist between these two states, and the practical advantages which result therefrom, which constitutes the art of electro-diagnosis. In this way, by demonstrating the histological condition of nerve and muscle, we obtain most valuable information concerning the functional activity, as well as the anatomical state of two great systems, namely—the peripheral nerves, and the muscles. This by itself opens out a wide field of practical utility, involving as it does the diagnosis and prognosis of injuries and diseases of all the nerve trunks of the body, and their terminations, also all the numerous affections to which muscular tissue is liable. Not only is such knowledge most important in determining the nature and extent of disease in these structures themselves, but recent investigations have indicated that from such alterations we can frequently infer the condition of distant parts and centres, such as the spinal cord and brain. It will be shown that in certain forms of paralysis from disease of the cord, trophic and electrical changes ensue, which are so characteristic as to enable us with great certainty to differentiate between them, and also from the peripheral lesions already referred to. Again, loss of motion from cerebral affections are succeeded by tolerably uniform results, totally different from those caused by disease in other portions of the nervous system. Thus, whether loss of voluntary motion is due to failure of muscle, peripheral nerve, cord, or brain, electrical tests in each give distinctive evidence, which often, by itself alone, determines the exact diagnosis, and without which a decision would be uncertain or impossible.

Such in general terms is the object we attempt to arrive at with electro-diagnosis. Like every other new art there are difficulties to be contended with in acquiring skill and dexterity in its application, and in eliciting useful facts. These, fortunately, are not insurmountable, but from the complicated nature of the structures involved, and the delicate manipulations necessary for their investigation,—knowledge, care, and patience—will always be required.

Before proceeding to the clinical aspects of electro-diagnosis, certain preliminary information is necessary on the part of those desiring to profit by its revelations. For the convenience of those who wish systematically to study this subject, it is proposed to consider the subject under the following heads. 1st. The apparatus essential for diagnostic purposes, without in any way entering upon the subject of electricity proper more than is necessary to give an intelligent explanation of the instruments required. 2nd. The anatomical knowledge necessary for conducting the enquiry, consisting of diagrams of the superficial muscles and nerves of the body, and the termination of the latter in the former. Also, without entering too deeply into topographical descriptions, to explain such details as are indispensable for actual practice. 3rd. The action of electricity on healthy tissues, and the results of physiological enquiry and experiment. 4th. The action of electricity on diseased tissues, and the results of pathological observation and research. 5th. A series of clinical cases in which the electrical reactions are illustrated in all the chief forms of paralysis from every source, with a consideration as to how far these phenomena assist us in diagnosis and prognosis.

CHAPTER II.

The Apparatus Necessary for Electro-Diagnosis.

In following out any method of research which requires for its elucidation the aid of physical agents, for success to be ensured, it is necessary that we should become acquainted with the general principles of the science which is to guide us, and with the construction of the instruments we employ. This is especially important in electrical investigations, as, in order to arrive at accurate conclusions, a certain knowledge of the subject, as well as manipulative dexterity is essential. It would be entirely out of place here to enter into details concerning either the science of electricity in general, or the mechanism of the various batteries and other apparatus in particular, as such are to be found in the numerous text-books and treatises which deal with these questions. In beginning this enquiry it must therefore be assumed that the student has already mastered the elements of the science of electricity, as well as the general method of its practical application in medicine. Without professing to enter at length into these important matters, it is at the same time necessary, in dealing with a special subject, to make some reference to the mechanical agents associated with it. As far as our knowledge of electro-diagnosis has yet advanced, certain forms of electricity and special mechanical contrivances are essential, and to these, and these alone, will reference be made, and only such brief considerations will be advanced as seems necessary for the guidance of the worker at the bed-side.

For the purposes of electro-diagnosis two forms of current are absolutely necessary,—the Induced or Faradic, and the Continuous or Galvanic.

The Induced or Faradic Current.

The apparatus from which this is derived consists of—1st, a battery of one, two, or more elements; 2nd, a primary coil of short thick wire; 3rd, a bundle of iron rods inside the primary coil; 4th, an automatic interruptor; 5th, a secondary coil of long thin wire; and 6th, an apparatus for changing the relative position between the primary and secondary coils, and thus regulating the strength of the induced current. The different arrangements of these essential parts constitute the variety of Faradic machines met with in commerce, and many of these have attained a most convenient and useful form. Whatever special shape the apparatus may take, certain particulars are requisite and absolutely essential for diagnostic purposes, and in selecting a battery care must be taken that none of these are absent. 1st. The battery must be sufficiently powerful, as for investigating the condition of diseased nerves and muscles we frequently require a current much stronger than is ever employed in treatment. 2nd. As the secondary current is usually selected for diagnosis, there must be some means of regulating its strength. At one time we may require a very feeble and delicate current, and at another the most powerful attainable from the battery. An apparatus is necessary not only to afford us each of these, but any intermediate strength that may be desired, and means must exist to enable us to pass from the weakest to the strongest applications very gradually, so as to avoid shocks and unnecessary pain. 3rd. A method of measuring and recording the strength of the secondary current, so that the same amount can again be referred to. This is easily accomplished by mechanical arrangements which regulate the distance between the two coils; and 4th. The interruptions of the current must be so arranged that they can be made as slow or as rapid as the operator pleases.

These various requirements are carried out more or less successfully in most of the machines to be obtained from ordinary makers, if not they are useless for the purposes of electro-diagnosis. The power of the Faradic current depends: 1st, on the strength of the battery current; 2nd, on the thickness and length of the primary coil; 3rd, on the thickness and length of the secondary coil, and 4th, on the relative position between the two coils. In the various machines as at present constructed, the coils can be arranged to a certainty, as well as the relations of one to the other, and the number of interruptions made to the current can be exactly determined; but we have no means of regulating the strength of the battery current which is to pass through the primary coil. This last can be measured by a galvanometer, but we have no means of so modifying its power as to obtain the exact amount of electricity we may require. A perfect instrument would be one in which a current that could be measured and regulated at will, was passed through the primary coil, the wire of which was of a known thickness and length, this inducing a current in a secondary coil also of ascertained composition. The secondary current thus induced with its interruptions would then be capable of measurement with exactitude. For some time past I have endeavoured to devise some means of carrying these requirements into execution, but hitherto without success, the great difficulty being to regulate the strength of the primary current. Doubtless those better acquainted with the subject of electro-physics than I profess to be, will some day be more fortunate, in which case they will provide the physician with a more accurate instrument than we now possess, and which will prove of the greatest practical and scientific value. At present we are dependent for the constancy of the primary current, on the stability of the cells employed, and although these are selected of such a kind as will vary in power as little as possible, still even these undergo constant changes under different conditions, which renders the secondary current variable. For practical purposes, however, it has been found that this arrangement, if it cannot be looked upon as an exact instrument for very delicate measurements, gives a current which is suitable for comparative and all ordinary clinical observations. As to the exact form of the battery to be selected, that depends upon the fancy of the purchaser, the the chief point to be attended to, is that it possesses all the requirements mentioned above. If size is of no object, and the battery is to be a stationary one, the larger the apparatus is the more durable and less likely to go out of order it will be. If portability is required there is no difficulty in suiting every taste.*

---

* A point not altogether unimportant is the cost of a Faradic apparatus. The price of most makers is unnecessarily exorbitant, as in reality the elements of which it is composed are not expensive. If the proper quarters are discovered a battery can be had for a very reasonable price. One suitable for all the purposes of diagnosis and treatment, capable, if carefully treated, of lasting in good condition for several years without repairs, should be purchased for a sum not exceeding two guineas. Gaiffe's induction apparatus can be bought for £1 1s., and is so far convenient that it can be carried in the pocket, and is therefore very useful in private practice. For hospital and consulting room work, a larger machine is preferable.

THE CONTINUOUS OR GALVANIC CURRENT.

This is derived from a battery properly so called, consisting of a number of elements arranged in series. A great variety of different forms of cell are in use for clinical purposes, a description, or even enumeration of which is here unnecessary. For electro-diagnosis certain essentials are required, whatever kind of galvanic battery is used. 1st. The current must be sufficiently powerful. This cannot be estimated by the number of cells, as the different kinds of elements vary greatly in strength, and the power of the same cell changes under certain conditions. For diagnostic purposes a battery must be capable of developing a force of at least 75 volts (the electrical unit of strength). For example, a Leclanché cell generates a strength of about 1½ volts, hence, if these elements are employed, a battery of 50 cells is required. Whatever form of cell be used, a proportionate number must be employed to make up the standard strength above stated. 2nd. Constancy and durability are of the greatest importance in medical batteries, and depend entirely upon the nature of the element used. Taking again the Leclanché cell as an example,—a battery of these has been found to be sufficiently constant for all practical purposes; and as to durability, it will last in good condition, with moderate use, for several years, and without requiring any repairs whatever. There are several modifications of the Leclanché element, which are said to be improvements, but in the event of any doubt existing as to the choice of a battery, the physician can scarcely be wrong in providing himself with one from that maker. 3rd. Portability.—A battery for the hospital and consulting room should consist of large stationary cells, as they are the cheapest, most durable, and less liable to get out of order. Even when portability is necessary, it is best not to procure too small elements as these generally prove unsatisfactory. A workable battery to be carried about, for diagnostic purposes is the ordinary 40 cell Leclanché.* 4th. Certain *accessories* are essential and must accompany the galvanic battery. These consist of—1st, a means of regulating the strength of the current; 2nd, a means of alternating or reversing the current; 3rd, a means of indicating and measuring the current; 4th, a means of interrupting the current.

1. *Current Graduation.*—The apparatus must be so arranged that we can apply the feeblest or the most powerful current according to necessity, and also any intermediate force that may be wished. It is important that this should be done very gradually, so that fine grades of power may be reached, and the change from weak to strong be accomplished without sudden shock. This may be effected by *a collector*—an instrument which enables the different cells to be put into action as desired. Thus the fewer the elements brought forward the weaker, and the larger the number the more powerful the current. The chief point to be noted is, that by this means not more than two cells at a time be arranged to advance at once, otherwise the changes are too sudden. The graduation of the current may also be carried out by *a rheostat*, which consists essentially of a resistance. This may be composed of thin wire, water, or other badly conducting substances, which can be graduated or measured according to necessity. Therefore the greater the resistance introduced into the circuit, the feebler the current will be, and the less the resistance the more powerful it is. Following this

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* The cost of this in a plain box without accessories should not exceed £4 10s.

principle instruments have been devised which are extremely convenient for practical purposes, and which can equally be applied for regulating the strength of both the faradic and galvanic currents. The rheostat has this advantage over the collector—that it is portable, and can be attached to any apparatus, while the latter is of necessity a fixture to its own particular battery. The first, more over, employs all the cells at once, while the last only uses those put in action. Finally, by having a powerful resistance included in the circuit, the modifying effects of the various conducting media throughout the body are less marked.

2. *Current Alternation.*—This consists in reversing the direction in which the current is flowing, so that the operator has the power of making a given electrode either the positive or negative pole. This is effected by means of *a commutator* or *alternator.* Of these, there are many different forms which for all essential purposes are equally useful. Perhaps the most convenient is the three stud commutator.

3. *Current Interruption.*—The object of this is to have the power of opening and closing the passage of the current at will, or of making these interruptions slow or rapid as required. There are also a great variety of instruments for effecting this end, but I shall only mention the two most suitable for diagnostic purposes. For slow interruptions an apparatus is introduced into the electrode which the operator holds in his hand, and by means of pressure on a spring with his finger, he can make or break the current as he wishes. This is called *the interrupting handle.* For rapid interruptions *a rheotome* is employed consisting of a toothed wheel, which when turned by a handle, quickly makes and breaks the current.

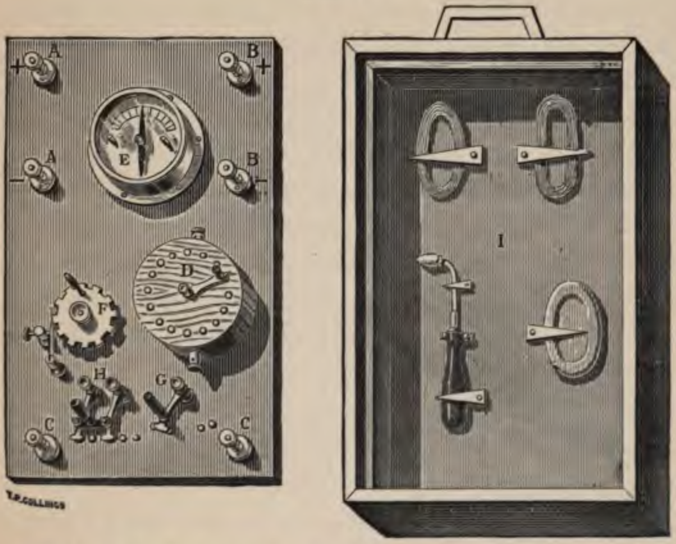
4. *Current Measurement.*—This is accomplished by means of

a galvanometer—an instrument which, if our present knowledge of electro-diagnosis has not rendered indispensable, is a great convenience in all electrical manipulations. Although it is of immense importance in treatment, owing to the vibratory oscillations of the needle, we are unable to measure the temporary applications of electricity in diagnosis, but doubtless as improvements are made in its construction, we shall become possessed of an instrument which will prove of great practical value. Although the galvanometer cannot be used for accurate measurements in diagnosis, it should always, if possible, be included in the circuit, as it is an index to the proper working of the battery, and a rough estimate of the strength of the current.

General Accessories.

Author's Element Board.—The accessories of the galvanic current just enumerated, are absolutely essential for the practice of electro-diagnosis. All of these, however, are rarely present in the ordinary batteries supplied for medical purposes; I have therefore had constructed an element board which contains all these necessaries, and possesses also other conveniences (fig. 1). This is arranged in a portable form and can be readily attached to any battery. To this is fixed wires from both the faradic and galvanic apparatus, and by means of a switch, either of the currents may be directed through the pair of rheophores to which the electrodes are attached. Both currents pass through the same rheostat which regulates their strength. The galvanic current further is connected with a galvanometer, a commutator, and a rheotome. Thus the two batteries being attached to the element board, either current can be passed through the electrodes, either can be regulated, measured, interrupted or alternated as desired.*

FIG. 1.



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* Fig 1. Author's element board. A A. Binding screws for attaching galvanic current. B. B. Binding screws for attaching faradic current. C. C. Binding screws for attaching the electrodes. D. A rheostat for regulating the strength of both galvanic and faradic currents. E. A galvanometer for measuring the strength of the galvanic current. F. A Rheotome for rapidly interrupting the galvanic current. G. A switch, the turning of which causes either the faradic or galvanic current to pass through C. C. H. A commutator I. Lid of element board containing handle, plate electrode, and rheophores.

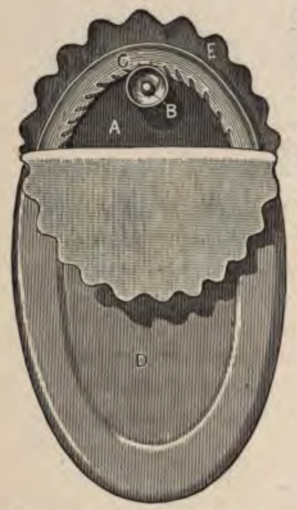
The full strength of both batteries should be applied to the attachment at the element board, that is, assuming the rheostat is sufficiently powerful to thoroughly control them. In the case of a strange instrument being used for the first time, this must be experimentally ascertained. This is simply effected by introducing the full resistance into the circuit, and by increasing the battery current till a minimum of action is ascertained through it. The apparatus is then in a controllable condition, for by reducing the resistance in the element board, the strength of the current is thereby increased.

This element board has been made by Mr. Thistleton, of Old Quebec Street, London.

Rheophores.—These are the wires by which the different accessories of the battery are connected with one another. These should consist of fine copper telegraph wire, insulated with india-rubber, and this further covered with some woolen, silk, or other material. The rheophores should be of different colours so as to avoid confusion in selecting the poles.

Electrodes.—For electro-diagnosis two forms of electrode are employed. One is a fixture on an indifferent part of the patient, such as the abdomen or back, the other is held in the hand of the operator, and is used by him for making observations. The most convenient form for the first is that of *a flat plate*, made of pliable metal, such as tin, and on the back of which is a connecting screw for the purpose of attaching the rheophore. This may be of any size or shape, but a suitable form is that of an oval about three inches long, and two and a half broad. This is enclosed in a moveable cover consisting, on one side of wash-leather, and on the other of water-proof sheeting. When the former is moistened and placed on the skin, the latter protects the clothes of the patient from wet. (Fig. 2).*

FIG. 2.



The other electrode, and that with which the operator conducts his manipulations, is called *the handle*. Gaiffe's interrupting electrode is that most commonly used. It consists of a solid handle in which is placed an ivory button connected with the interrupting apparatus. The whole is surmounted by an olive-shaped carbon head, covered with wash-leather, which, when moistened, can be applied to the surface of the skin. (Fig. 3).*

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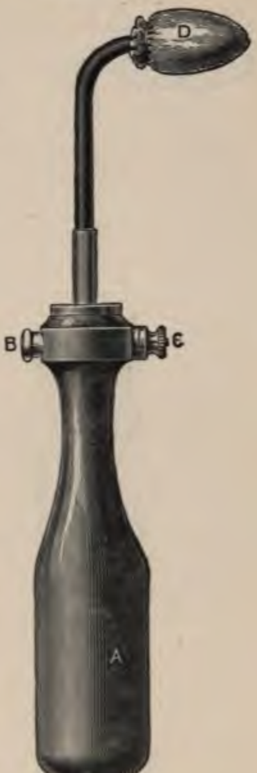
* Fig. 2.—Flat plate electrode (half-size). A. Metal plate. B. Binding screw. C. Wash-leather covering for front of plate. D. Water-proof sheeting for back of movable covering. E. Wash-leather portion of front of D.

Fig. 3.



It is scarcely necessary to observe that the old-fashioned system of dabbing sponges fixed in cups on the skin is utterly useless for all delicate diagnostic investigations.

Author's Combined Electrode.—Those who have practical dealings with the electrical apparatus now in use, will doubtless have satisfied themselves of the many inconveniences inseparable from it. As before stated, most of the batteries supplied for medical purposes are wanting in some or all of the accessories which are absolutely indispensable for diagnosis. Even the element board already described which supplies these deficiencies is not without its disadvantages. The practical worker at the bed-side will have experienced the difficulty and inconvenience of using one hand for the handle, and the other at a neighbouring table for moving his rheostat, alternator, etc. Such manipulations are not only troublesome, but lead to inaccuracy, as then the attention of the observer is divided, and his position has to be constantly rearranged and altered, which render delicate experiments very difficult. To obviate these disadvantages I have had an instrument constructed consisting of a handle in which all the essential accessories for diagnosis are inserted, and all of which can be worked by one hand (fig. 4). This acts as an electrode, and also interrupts, alternates, and regulates the strength of both the faradic and galvanic currents. The details of the apparatus are so arranged that the observer holding the instrument in his hand and thus applying it to a muscle or nerve, can, by a movement of his thumb, reverse, open or close, increase or diminish the current, without removing the electrode from the tissues to which it is applied, and without occupying his attention or movements beyond the simple action of one finger. It has also the important advantage that it is portable, and can he attached to any battery, thus rendering the observer independent of the deficiences of most apparatus. As a matter of practical experience I have employed this combined electrode for some time, and find that it successfully performs the ends for which it was constructed.*

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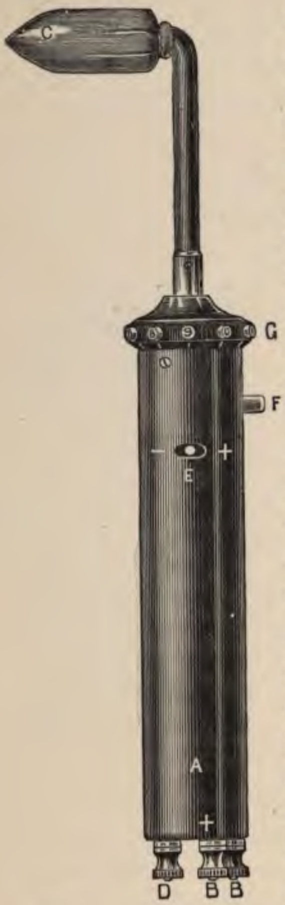
* Fig. 3.—Gaiffe's interrupting handle (half size). A. Solid handle. B. Interruptor. C. Binding screw. D. Olive-headed electrode covered with wash-leather.

Fig. 4.



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* Fig. 4. *Author's Combined Electrode* (half size).—A. The handle. B.B. Are two connecting screws to which are attached the positive and negative

CHAPTER III.

ANATOMICAL KNOWLEDGE NECESSARY FOR ELECTRO-DIAGNOSIS.

IN electro-diagnostic investigations we have to deal with muscles and nerves. As our object is to limit the stimulating effects of the current to the point at which the electrode

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poles of the battery. C. Is a metal or carbon point covered with wash-leather. In the figure this is of a convenient shape for electro-diagnostic purposes, by which, either a very fine point or a considerable surface can be applied to the skin. This may be unscrewed and other heads of different shapes and sizes fixed on as necessity may require. D. Is a binding screw for the other electrode which is applied to the patient in order to complete the circuit. E. Is a lever for alternating the current, when moved towards + the point C is the positive, and when towards — it is the negative pole. F. Is a peg which when pressed down, closes, and when it moves back by means of a spring, breaks the circuit. By means of this, the current can be interrupted as slowly, or as quickly, up to a certain point, as is desired. G. Is a revolving wheel in connection with a rheostat in its interior. This consists of ten sections numbered respectively, and each of these, by throwing a unit of resistance into the circuit, in consequence diminishes the strength of the current, and *vice versa*. This rheostat does not profess to be an exact or measurable amount of resistance, but is simply a means of gradually increasing and diminishing the strength of the current for practical purposes. It has been so arranged that its power is convenient for clinical use. For example, when the instrument is attached to the full power of a 40 cell Leclanché battery, and the entire resistance introduced into the circuit, a minimum amount of sensation is perceptible to the skin. As each division of the wheel is turned, a tenth of the whole resistance is taken from the circuit, and consequently the current increases in strength, till when it reaches the last section where there is no resistance the full power of the 40 cells is obtained. More correctly estimated by means of a galvanometer, the properties of the rheostat may be thus stated. Supposing the current from the 40 cells, passing through the human body to indicate 12 M. V., one unit of resistance of the rheostat introduced into the circuit, reduces the reading to 11 M.V,, and so on till when the whole resistance is included 2 M.V. is the result. Hence practically the resistance of this electrode sufficiently conis applied, it is evident that this can only be satisfactorily accomplished in those which are superficial and lying immediately under the skin. The muscles more deeply seated cannot be directly influenced for diagnostic purposes, but may be reached only through the medium of the nerves. It is not proposed to give a detailed topographical account of all these structures as it is assumed that the student is already acquainted with general anatomy, at the same time so essential is a knowledge of the exact position of the various superficial muscles and nerves of the body, that I have arranged a series of diagrams which show at a glance the chief points necessary to be known, and only such detailed description on those particulars will be added, a want of knowledge of which would render all progress in the enquiry impossible.

SUPERFICIAL MUSCLES.

In the plates, is sketched the outline of all the chief superficial muscles of the body, and those therefore which can be influenced directly by the electrical current. It would be impossible and unnecessary in a treatise like the present to describe the action of each of these in detail. M. Duchenne* in a book of 872 pages, has elaborately enumerated the physiological and mechanical function of most of them, to which work the reader is referred for all necessary knowledge on the subject. For practical purposes we can readily understand the direct effects of the contraction of any particular muscle, as if its origin and insertion be known, the

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trols for diagnostic purposes, a current of from 40 to 50 cells, to which it may be at once attached. As to the faradic current, the strength from the battery to be employed must be experimentally ascertained as already indicated, which can be accomplished in a few moments.

This instrument has been made by Mr. Hawksley, Oxford Street, London.

* *Physiologie des Movements.* Paris, 1867.

effects of its shortening must be apparent. It is of course upon the fleshy substance of the muscle that observations are made, tendon not being contractile in the proper sense of the word.

SUPERFICIAL MOTOR POINTS OF MUSCLE.

Each muscle is supplied by one or more branches of nerve derived from the main trunk, and the exact spot where these enter its substance is called the *motor point*. As will subsequently be seen, in producing muscular contractions, the position of the entrance of the nerve filament is a matter of some importance, irritation there causing totally different effects from stimulation of the fibres themselves. We owe to Duchenne and Ziemssen, more particularly, most of our accurate knowledge on this subject, these observers having experimentally ascertained the motor points of the superficial muscles of the body. In the plates the position of these have as nearly as possible been indicated by a black dot. It is difficult to localise them on paper with mathematical accuracy, as they vary considerably in different individuals; but after numerous experiments and observations made by myself, I believe the figures here given present a fair general idea of the average position they occupy. Some muscles have practically no motor points, that is they are not superficial, hence such cannot be made to contract through nervous influence, except at the nerve-trunk above.

SUPERFICIAL MOTOR NERVE-TRUNKS.

As a knowledge of the exact position of the motor nerve-trunks, and the groups of muscles they supply is indispensable for diagnostic purposes, I shall enter more fully into particulars on this subject, at the same time avoiding all such anatomical details as are not absolutely essential. Fortunately most of the motor nerve-trunks which supply the superficial muscles lie under the skin, at some part of their course, and can be felt there with the finger, or are so close to it as to be readily reached by the electric current. Some, however, are too deeply seated to be practically available for our purpose. It is only the former that we have to study, and in the plates these are indicated by black lines.

1. SUPERFICIAL MOTOR NERVE-TRUNKS OF THE HEAD AND NECK. (*Plate* 1).

The Facial Nerve. The main trunk of this nerve lies in the substance of the parotid gland where it divides into two branches, the tempero-facial and the cervico-facial. These two branches become superficial on leaving the gland and lie between the skin and the ramus of the jaw, where they can be readily stimulated. (*a.*) *The Tempero-Facial branch,* is found at the posterior edge of the ramus of the jaw, a little below the level of the lower margin of the lobe of the ear. Its branches spread out from this point in a fan-shaped manner, and each can be easily reached as desired. This nerve supplies the occipito-frontalis, orbicularis palpebrarum, corrugator supercilii, buccinator, orbicularis, levator labii superioris and levator anguli oris muscles. In short it supplies motor fibres to the ear, scalp, mouth, nose, and eyelids, and its irritation causes contraction of all the above-named muscles. (*b.*) *The Cervico-Facial branch,* is found at the posterior edge of the ramus of the jaw a little above its angle. It supplies the lower part of the face and the upper part of the platysma myoides muscle. In the same manner as the other branch of the facial, this spreads out into a fan-shaped series of filaments, which, if necessary, may be separately stimulated.

The Spinal Accessory Nerve. The external branch of this nerve after perforating the sterno-mastoid, becomes superficial at the posterior border of that muscle, a little above its middle, and from this proceeds obliquely downwards and backwards towards the trapezius. At any part of this course it may be stimulated with electricity. It supplies the sterno-mastoid and trapezius muscles. When irritated through the former muscle, there is flexion of the cervical spine, pushing forward of the lower jaw, turning of the head on its axis the face looking to the opposite side, raising of the shoulder, and approximation of the scapula to the spine. Irritation below the sterno-mastoid muscle causes the same, only the cervical spine is extended instead of flexed, and the head is inclined backwards and towards the side stimulated.

The Cervical Plexus, consists of several branches running obliquely downwards and backwards between the sterno-mastoid and trapezius muscles, each of which may be stimulated separately. (*a.*) *The Superficial Cervical branch* turns forward from behind the sterno-mastoid about its middle, and lies horizontally on the surface of that muscle, where it can be reached for electrical purposes. It supplies the platysma myoides muscle, and its irritation causes puckering of the integument of the neck. (*b.*) *Branch to the Levator Anguli Scapulæ Muscle.* This appears superficially at the posterior border of the sterno-mastoid a little below the nerve last described, and runs obliquely downwards and backwards towards the trapezius. As its name implies it supplies the levator anguli scapulæ muscle, and its irritation causes the shoulder to be raised. (*c.*) *Branch to Trapezius.* This lies in the same oblique direction close below the filament just described, and supplies the trapezius muscle. Its irritation causes the shoulder to be raised, and the head to be drawn backwards and towards the side stimulated.

2. SUPERFICIAL MOTOR NERVE-TRUNKS OF THE UPPER EXTREMITY. (*Plates* 2 and 3).

The Ulnar Nerve is superficial from the axilla to the elbow, at which latter place it lies between the olecranon process and the inner condyle of the humerus. Immediately above this spot its trunk can be readily felt with the finger through the skin, and this is a convenient position for the application of the electrode. The ulnar nerve supplies the following muscles :—flexor carpi ulnaris, part of flexor profundus digitorum, flexor brevis minimi digiti, abductor minimi digiti, all the interrossei, the two inner lumbricales, adductor pollicis, inner head of flexor brevis pollicis and palmaris brevis. Its irritation above the elbow causes flexion of the ulnar side of the hand, slight flexion of all the fingers at their metacarpophalangeal joints, flexion and opposition of the little finger, hollowing of the hand, and adduction and slight flexion of the thumb.

The ulnar nerve is also superficial a little below the middle of the forearm, and may be reached at the outer margin of the flexor carpi ulnaris muscle, about two inches above the wrist joint. Its irritation here flexes and opposes the little finger, hollows the hand, adducts and slightly flexes the thumb.

The Median Nerve is found superficially about two inches above the front of the elbow joint, a little internal to the inner edge of the biceps muscle. It can here be readily felt by the finger through the skin to the inner side of the artery. It supplies all the pronators and flexors of the forearm, (except the flexor carpi ulnaris and part of the flexor profundus digitorum which are nourished by the ulnar), the abductor, opponens, and the outer head of the flexor brevis, pollicis, and the first and second lumbricales. Its irritation above the elbow causes pronation of the forearm, flexion of the radial side of the hand, flexion of the fingers, abduction, opposition, and slight flexion of the thumb.

The median nerve may also be reached about an inch above the wrist joint, between the tendons of the flexor carpi radialis and the pulmaris longus muscles. Its irritation here causes abduction, opposition, and slight flexion of the thumb.

The Musculo-spiral Nerve is very important in pathological states, but unfortunately is deeply seated and not always readily accessible. In thin persons it can usually be reached and stimulated; but in fat and very muscular individuals it may be difficult to do so completely. It always requires care to ascertain the exact spot, which is a very limited one, the irritation of which produces the typical muscular contractions. It is reached by applying the electrode about three inches above the external condyle of the humerus on the outer and posterior aspect of the limb, at the edge of the triceps, between it and the brachialis anticus muscles. With the finger can sometimes be felt the depression in the shaft of the humerus round which the nerve winds obliquely from underneath the triceps, to the space between it, and the upper part of the supinator longus muscle. It supplies the triceps, auconeus, the supinators of the forearm, all the extensors of the hand, fingers and thumb. Its irritation at the point described, causes supination of the forearm and extension of the hand, fingers, and thumb.

3. Superficial Motor Nerve-Trunks of the Lower Extremity. (*Plates* 4 and 5).

The Anterior Crural Nerve becomes superficial at the lower border of Poupart's ligament, a little to the outside of its middle line, where it can be felt with the finger external to the artery. Usually here there are two or three large branches, to each or all of which the electrode can be conveniently applied. It supplies the iliacus, part of the pectineus, sartorius, rectus, vastus externus, and crureus muscles. Its irritation at the above-mentioned place causes obvious contractions of the muscles in front of the thigh, and extends the leg.

The Internal Popliteal Nerve passes down the middle of the popliteal space from between the semitendinosus and biceps muscles. It can be there felt with the finger, and the electrode is best applied about two inches above the junction of the two heads of the gastrocnemius muscle in the middle line. It supplies the gastrocnemius, plantaris, soleus, popliteus, tibialis posticus, flexor longus digitorum, flexor longus pollicis, flexor brevis pollicis, abductor pollicis, adductor pollicis, flexor brevis digitorum, flexor brevis minimi digiti, flexor accessorius, transversales pedis, and all the interossei and lumbrical muscles; in short all the muscles at the back of the leg and sole of the foot. Its irritation produces flexion of the foot and toes.

The External Popliteal Nerve is to be found in the popliteal space, running obliquely outwards over the outer head of the gastrocnemius, and at the lower and inner edge of the tendon of the biceps muscle, and here it can be distinguished with the finger. It supplies the peroneus longus and brevis, tibialis anticus, extensor longus digitorum, and extensor longus and brevis pollicis muscles. Its irritation causes extension of the foot and toes. *The Peroneal Nerve*, a branch of the external popliteal, may be specially reached below the outer and posterior aspect of the head of the fibula. It supplies the peronei muscles, and its irritation causes extension of the foot outwards.

DEEP SEATED MOTOR NERVE-TRUNKS.

A large number of the motor nerve-trunks of the body are so deeply seated, that it is impossible to utilize them for diagnostic purposes. These are covered with muscles and other structures requiring a powerful current to penetrate through them, which renders accurate conclusions impracticable, as this by its diffusion, so reacts on the neighbouring tissues, as to prevent a strict localisation of action on the nerve under observation. Those superficial trunks which may be considered as always available for the purposes of diagnosis have already been enumerated. There are however some, which, although under ordinary circumstances are not readily reached, may in special cases be irritated by electricity. For example, in a well developed and muscular subject, the hypoglossal nerve is completely covered with a layer of muscle, so that direct stimulation with a moderate current is impossible. In very thin persons, or when disease has caused emaciation of the muscles, this nerve may be practically reached through their attenuated substance. In particular instances a knowledge of this may be of importance, as in a case of bulbar paralysis. As a rule, however, those nerves which have to be acted upon through a thick muscular medium, which varies in different diseases are not to be depended upon for accurate diagnostic purposes. For this reason it has not been thought necessary to give a detailed description of these semi-superficial nerve-trunks; but the position of the most important has been marked in the plates by a +. A knowledge of these is more necessary for therapeutics than for diagnosis.

CHAPTER IV.

METHOD OF APPLYING ELECTRICITY IN DIAGNOSIS.

IT has been urged against the art of electro-diagnosis that the difficulty, trouble, and time expended in its use, is out of all proportion to the practical advantages obtained. Up to a comparatively recent period this cannot be altogether denied, but it is the purpose of this treatise to indicate the value of the knowledge we obtain by this form of investigation, and to endeavour to simplify the means of arriving at it. The difficulties hitherto have been chiefly due to the fact, that this branch of enquiry being new, the instruments at our disposal have been imperfect and unsatisfactory, and even now in great measure still are so. Also few medical men have been instructed in their use, and those who have paid special attention to the subject have been compelled to educate themselves in the art. With the more perfect apparatus now at our disposal, improved methods of research, and an extended general knowledge of the subject, it will be found that the difficulties in the details of electro-diagnosis, like those of most other novelties, will disappear; and so far from adding to the already overburdened curriculum of the student and practitioner, it will be found in reality a means of limiting his labour in the investigation of disease. As the usefulness of this procedure depends upon the accuracy and method in which it is performed, and as it is important that this should be conducted with the least trouble and in the shortest time, I make no excuse for entering into minute details of the application of electricity for the purposes of diagnosis.

As has already been indicated the object to be arrived at, is a knowledge of the exact anatomical condition of nerve and muscle, from which we infer their functional state, and as a consequence many other important questions connected with disease. We have therefore, with suitable applications, to stimulate both nerve and muscle, and we judge of the effects of the irritation by the contraction of the latter. The sequence of events which ensues will be fully described in succeeding chapters, in the meantime we devote ourselves to manipulative details.

METHODS OF APPLICATION.

1. *The Indirect Method.* This consists in irritating the trunk of the nerve at some distance from the muscle or muscles it supplies. For example, when the current is applied to the trunk of the ulnar nerve above the elbow, all the muscles receiving their nervous supply from below this point, are at once put into a state of contraction, and certain movements of the hand and fingers ensue.

2. *The Direct Method.* In this, the current is applied to the muscle itself. There are two forms, *a.* the direct *extra*-muscular, in which a motor point is stimulated, consequently the main bulk of the muscle contracts, and, *b.* the direct *intra*-muscular, in which the irritation is applied to the muscular fibre itself, and not to any special nervous filament, hence there is contraction only of the fibres immediately under the electrode. This last is subject to the law of diffusion of currents which will be afterwards discussed.

3. *The Polar Method.* In acting upon nerve or muscle we may apply both poles of the battery to their substance, and until recently this has been the method of procedure. By far the most effective and exact system is to adopt what is called the Polar Method, by which we obtain the specific

effects of each pole of the battery according to desire. This is carried out by placing one electrode on the nerve or muscle we wish to stimulate, and the other on some distant part of the body, thus eliminating its effects. In this way the action of the two poles is not confused, as they are liable to be when placed close together, and we can judge the result of each separately.

Practical details in the Method of Procedure.

The patient must be placed in a good light, both sides of his body being equally illuminated. If the head or upper part of the trunk is to be investigated, he may stand or sit as is most convenient. The upper extremities are best examined with the patient sitting on one chair, with his forearms resting on the back of another. To test the condition of the lower part of the trunk, and the inferior extremities, the most suitable is the recumbant posture. In every case, all the muscles should be in a state of relaxation, the patient should be directed to keep himself perfectly at rest, and both sides of the body should be placed in the same position, and under similar circumstances. The operator while sitting or standing near the patient, must have all his apparatus around him within easy reach, and in delicate investigations the necessity of having properly adjusted instruments, combined with manipulative dexterity, is of great importance. Throughout the entire procedure great care must be taken, to keep both electrodes and skin well moistened. Dry epidermis is an extremely bad conductor, and if not thoroughly wetted the current of electricity will fail to penetrate it, in order to reach the nerve or muscle. In such cases great pain is caused, owing to the current being arrested at the integument, and acting on its sensitive nerves. Hence throughout the séance, fluid must be used with prodigality. For all practical purposes, simple water is all that is necessary. If acid or salt be added its power of conduction is improved. A small porringer of water close at hand, is therefore a 'sine qua non,' into which must frequently be dipped the electrode with which we are working. It is scarcely necessary to indicate the employment of towels suitably distributed, to avoid wetting the bedclothes or dress of the patient.

When the upper part of the body is being examined, a suitable position on which to place the flat plate electrode, is the nape of the neck. If the patient is clothed, this can conveniently be slipped inside his collar, and is thus held firmly in position. If he is undressed, or if the clothes fail to secure the plate, it must be tied on. This is best effected by means of a soft-knitted band, like a broad garter sufficient to go once or twice round the neck, and securely fastened. Handkerchiefs, bandages, &c., are unsatisfactory, as on the one hand they either suffocate the patient, or on the other the plate is not firmly held in position. The knitted garter is soft and elastic and thus tightly fixes the electrode without discomfort. This may appear a trifling detail, but it is the non-observance of such little matters, as ascertained by experience, which constitute the troubles, expend the time, and falsify the results of electrical investigation.

If the lower part of the body is to be tested, the patient, if in bed, may place the flat plate over the sacrum, and keep it in position by simply lying upon it, or he may apply it to the sternum or front of the abdomen, and hold it there with his hand. In careful clinical observations it is best to act always under the same circumstances, and altogether the most central and suitable position for this electrode in all cases and for all parts of the body, is the front of the abdomen.

Having then firmly secured the well moistened plate, we proceed with the handle electrode, also soaked with water, to systematically investigate the effects of both currents on the nerves and muscles. The usual order of procedure is as follows; 1. Faradism to the nerve trunks. 2. Faradism to the motor points. 3. Faradism to muscular tissues. 4. Galvanism, applied in the same order.

1. *Faradism to Nerve-Trunks.*—The negative pole of the induced secondary current is generally used as the excitor, and to avoid confusion, it is best to make a rule always to select it. The interruptions should be rapid, and for ordinary purposes the instrument in this respect should always be kept at a fixed standard. In commencing operations, it is advisable to begin with a known healthy nerve, so that finding its reactions, we may compare them with those of the one diseased. Place the well-moistened, leather covered end of the handle electrode, accurately on that point, over which it has been ascertained the nerve lies. It must be firmly pressed down, so as to facilitate the passage of the current through the skin. Having got this firmly in position, by means of the interrupter, suddenly complete the circuit, without relaxing the pressure on the nerve, and still keeping the electrode in its place. A very weak current from the battery is started. If the shock thus given produces no effect, the strength of the current is increased, till some contraction of the muscles supplied by the nerve, is seen. The effects are to be observed and compared with the other side, or other nerves. Again, different strengths should be employed, with a view of ascertaining the reactions of the muscles under different powers of stimulation. It must be remembered that powerful faradic irritation of a nerve, is very painful, and very rarely of any use, so that care must be taken always to begin with feeble currents, and gradually increase them until the requisite strength is obtained. If the operator thus acts, he does not in the least alarm the patient, who soon finds that the pro-

cedure, if a little unpleasant, is practically painless. If, however, he starts by unduly causing pain or sudden shocks, the subject of observation, especially if a woman or child, is frightened and restless, and the tremor and involuntary movements thus induced, greatly militate against accurate observation. Finally, and more particularly when the nerve is diseased, the effects of varied interruptions of the current must be noted, as in certain conditions, when these are rapid, they are followed by no response, but if slow, may be succeeded by muscular contractions.

In noting the muscular contractions, much caution must be exercised, otherwise great errors may be made. In stimulating a nerve, it is necessary to know the muscles it supplies, and their action as a result of irritation, as these and these alone are to be for the time attended to. Especially when strong currents are used, there is great diffusion of the electricity, and the neighbouring tissues are influenced as well as the nerve we are investigating, and the effects of the latter must be carefully separated from the former. To take an example; suppose the ulnar nerve is being acted upon above the elbow with a pretty strong current. In health, all the muscles which it supplies will contract vigorously. In addition, however, the muscles of the upper arm which are in direct contact with the electrode, will also act. These last have to be eliminated in the observation. In health this is not difficult, but in disease, when certain nerve fibres or muscles are affected it is more so. Suppose again, that all the muscles supplied by the ulnar nerve were diseased, and a strong current was applied to its trunk, although it would produce no contraction of the flexors, it might by transmission induce action of others such as the extensors of the hand. This has to be noted, and not confounded with the effects of the nerve under consideration. The complete distribution has also to be observed, and the perfect or insufficient action watched. For example, if, on irritating the ulnar, there was contraction of the muscles of the fingers, but no action on the hand, we should conclude that the flexor of the wrist was not performing its function, as it is supplied by the nerve stimulated.

As a rule a prolonged application is not necessary, but sufficient only to see the marked effect of muscular contractions, and judge of its vigour. One second may roughly be estimated as a convenient length of application, for this to be tested in health, but this will vary according to circumstances in disease. Having obtained the strength of the current necessary to produce definite effects, and having observed and estimated the extent of these, a comparison has to be made with the other side of the body. To arrive at accurate conclusions, precisely the same conditions must be employed on both sides. The same spot of the nerve must be selected, the same amount of pressure applied, and strength of current used. In this way if the disease is one-sided, the difference between it and the normal state, may be readily estimated. In comparing two places, some physicians use a double rheophore, and hold an electrode in each hand. I confess I prefer to deal with one only, finding it difficult enough to select the exact spot under which the nerve lies, and to keep there, with a single, much more than with a double instrument. Also the conducting power of the two electrodes may vary and thus complicate matters. In short, if the phenomena on one side be first carefully ascertained, there is little practical difficulty in afterwards comparing it with the other, with the same electrode. If the disease exists on both sides of the body, a recognition of abnormal conditions is more difficult. If we, in such a case, cannot compare one side with the other, in order to obtain a normal standard, we are obliged to take as such, some of the other healthy nerves of the body. This requires great knowledge and experience, for as we shall afterwards see, owing to varying physical conditions, these differ in their sensitiveness to excitation In a series of observations made by myself and referred to in a subsequent Chapter (page 48). I have endeavoured to show that a comparison may be made between the relative excitability of all the great nerve trunks of the body, which if not of perfect scientific accuracy, is useful for practical diagnostic purposes. Hence, if both sides are affected, we may, subject to certain restrictions, compare the diseased with other healthy portions of the body.

2. *Faradism to Motor Points.*—To stimulate the motor points of the muscles, precisely the same steps are to be taken. The sharp end of the electrode is to be firmly placed as near the spot as possible, and if this does not produce the desired effect, namely, contraction of the mass of the muscle, it must be moved about in the neighbourhood, till it is evident the motor nerve is being irritated. Considering that we cannot actually see the exact position, even of the muscles themselves, through the skin; it may be easily conceived that it is often no easy matter to arrive at the exact spot at which its nerve enters, and more especially as this may vary in different individuals. Like most other difficulties, this is only to be overcome by an intimate knowledge of the parts, and by constant practise, through which only, dexterity and accuracy is to be obtained. Although a knowledge of these motor points is scientifically of great importance, it must be admitted that in practise it is not always absolutely essential. Having ascertained the function of the nerve trunk, we have thus already arrived at the action of its branches, in other words, the motor points. It must, however, be remembered that

there are many portions of the body and many muscles, to whose nerve trunks we have no means of reaching, in which case our only method for determining the condition of the peripheral nerves, is by stimulating the motor points. In any case, the greatest care must always be taken in comparing the two sides of the body, to place the electrode on exactly the same point of each muscle. For example, in testing the contractility of say the supinator longus, if on one side we applied the irritation at the motor point, and on the other at the muscular fibre, the effects of the stimulation with the same current would be very different, although the muscle and nerve might in reality be perfectly normal.

3. *Faradism to Voluntary Muscle.*—The electrode is placed over the muscular substance which is thus directly stimulated. Precisely the same methods are employed, and observations made, as those already described with regard to nerves, as in faradising a muscle we are in reality acting upon the intra-muscular nerves, there being no true Farado-muscular excitability. Each muscle must be separately treated, and its specific effects carefully observed, and great caution is to be exercised not to confound this with the responses of its neighbours. In disease especially this is of the greatest importance. For example, when the *extensors* are destroyed, as in lead paralysis, application to them of a strong current, may induce *flexion* of the hand. This indicates that the current has passed through the weakened extensors without effect on them, but inducing contractions of the flexors by transmission. Care has also to be taken that in comparing the muscles of two sides, that the electrode is placed on exactly the same spot of each muscle, for not only does the bulk of the fibres vary at different parts, but branches of the motor nerve are here and there superficial, and may be

stimulated on one side and not on the other, thus rendering a comparison fallacious. In very small muscles, the point of the olive shaped electrode must be used, in order to limit the current as much as possible. In the larger muscles, as great a surface as the electrode permits, should be applied. Although the whole of the muscle may be tested, practically, the most fleshy part is the most suitable position.

In certain circumstances the effects of varying the interruptions of the induced current should be ascertained. This may be slowly performed by moving the vibrator of the coil with the finger; if rapidity is required this must be adjusted by means of the screw attached to the instrument.

In making subsequent examinations of the patient, it is of great importance to ascertain whether any change, either of degree or kind, has taken place since the observation on a former occasion. The faradic instruments as at present constructed are unfortunately not sufficiently exact for the first of these purposes. For example, if we examine a nerve with a certain strength of induced electricity, we have no means of applying exactly the same amount, say six months afterwards, and noting the difference of degree at the two periods. It is true that for most practical purposes, we can roughly estimate the changes which thus ensue, but if a more perfect instrument could be devised which would fulfil this end, it is needless to point out its great importance as regards diagnosis and prognosis.

The sensibility of different portions of the body vary, the face, and head generally, being especially sensitive, so that too strong a current must be avoided. It is always advisable that the operator, before making applications to the patient, should test the strength of the current upon himself. This he can always do, (assuming the plate to be already attached to the patient), by simply placing his palm on the skin of the latter, and touching with the electrode the back of his own hand. This is not only a test for the effects on the sensibility, but is also a guide to its effect in contracting muscles. Too much confidence must not, however, be placed on this last, as the skin and other conducting media, may differ greatly in the doctor and his patient.

The chief points to observe in the application of the faradic current, are. To the nerve trunk:—1st. The amount of muscular contraction to a given strength of current. 2nd. The comparison of this, with that of the opposite side. 3rd. The comparison between it and other healthy nerves. 4th. Whether all the muscles supplied by the nerve contract, note deficiency of special muscles, or part of muscle. To the motor points, and muscles, observe:—1st. The vigour of contraction in the whole or part of the muscle. 2nd. The comparison with the opposite side. 3rd. The comparison with the other healthy motor points and muscles. 4th. The comparison of direct effect, from the indirect irritation of the nerve trunks. 5th. That the actions of other muscles from diffusion of the current, are not confounded with that one under observation. 6th. The effects of slow or rapid interruptions.

4. *Galvanism to nerve trunk, motor point, and muscle.*—The method of applying galvanism to nerve trunk, motor point, and muscle is, as regards mechanical manipulations, exactly the same as of faradism. The chief difference is, that the special effects of each pole of the battery has to be noted. This is done through the medium of the commutator. Having placed the electrode on the nerve or muscle, as already described, it is made positive or negative as required, and by means of the interrupting handle, the shocks in each case are observed. The results of opening and

closing the current are to be noted. As with faradism begin with a weak current, test each pole separately, closing and opening in turn. Gradually increase its strength, and observe when muscular contraction first appears, at which pole, and whether at its closure or opening. Continue to augment the current, still watching the order in which the contractions appear, their degree, their duration, and their character generally. What may be expected to take place will be detailed in the next chapter. The effects of variously interrupting the galvanic current must also not be forgotten. For slow interruptions, the ordinary handle is used, and these are made with the finger. When great rapidity is required, the rheotome is perhaps the most convenient method of producing it. We have at present no accurate practical instrument, except clockwork, for measuring the number of interruptions, so that we can only speak of, very slow, slow, medium, rapid, and other such somewhat inexact terms. With regard to measuring the strength of the galvanic current, this can be very accurately done by means of the galvanometer in therapeutics and other prolonged applications, but for the purposes of diagnosis in the manner already detailed, we have not, unfortunately, any satisfactory method. As here the effects are of very brief duration, and as the needle of the galvanometer oscillates, it is difficult to measure the current sufficiently rapidly. Improvement of the instrument may, we hope, soon be made, by which it may take instantaneous measurements, a discovery which would prove of immense practical value.

All the other details of the application of the galvanic current, and the cautions to be observed, are the same as with faradism. With galvanism the special points to be noted are:—1st. The amount of contraction of each pole as compared with the healthy side. 2nd. The amount of contraction of one pole as compared with the other. 3rd. The amount of contraction at closure of the current, as compared with the opening of it. 4th. The nature of the contraction, whether rapid or sluggish, complete or incomplete, etc.; and 5th. The effects of varied rapidity in the number of interruptions.

CHAPTER V.

ELECTRICAL REACTIONS IN HEALTH.

THE two forms of electricity already described, and applied in the manner indicated, produce certain definite and well marked phenomena on the different tissues of the healthy subject. For the present purpose it is sufficient to know their effects on the spinal cord, motor nerve, and voluntary muscle.

1. SPINAL CORD.

If a healthy spinal cord be exposed by dissection, and electricity applied to its substance, there are vigorous contractions of all the muscles of the body, supplied by the nerves derived from and below the point irritated. The responses to the different currents are of the same character as those about to be described as occurring with motor nerve. In the human subject applications to the spinal cord are never made for diagnostic purposes.

2. MOTOR NERVE.

On irritating a motor nerve with electricity, the only visible phenomenon which follows is, contraction of all the muscles which it supplies. Certain other changes take place in the nerve itself, but for our present purpose, we have only to study the behaviour of the muscular contraction. This takes place as a result of variations in the density of the current, and therefore these muscular contractions only occur at its closure and opening, and their amount is practically in proportion to the strength and suddenness of its modifications. While the current is constant, and flowing through the nerve without interruptions, there is no response. Electricity does not cause muscular contractions merely by the power the nerve possesses of carrying its influence to the muscles, but by its specific action in stimulating the nervous elements into functional activity. This is evidenced by the fact, that if a nerve be injured or diseased, on electric stimulation no contractions are produced, although its power of conducting the current is in no way interfered with. It is also shown by the further from the muscle a healthy nerve is irritated, the greater is the effect produced, and this is increased if a portion of the nerve centre be included in the circuit.

Effects of Faradism.—If, by dissection, a motor nerve be exposed and irritated with the faradic current, the following action ensues. Each shock produces a muscular contraction, immediately followed by relaxation, but as in the ordinary apparatus, these interruptions rapidly succeed one another, there are no apparent intermissions, one contraction not having ceased before another has taken place. Hence there is tetanus of the muscle, and this continues all the time the induced current is passing. The intensity of the tetanic spasm is in proportion to the strength of the current, and the rapidity of the interruptions.

In the human subject, where the nerve is reached through the skin and other superficial tissues, the action is precisely the same, tetanic spasm taking place in all the muscles supplied by the nerve, the trunk of which is irritated by the induced current. Rapidly interrupted faradism is the most powerful electrical stimulant to healthy nerve.

Effects of Galvanism—The action of the galvanic current on dissected out motor nerve is very different and much more complicated. The effects, however, are perfectly definite, and constitute what is termed the law of contraction of motor nerve and muscle. When this is applied with moderate power to a nerve, muscular contractions ensue, but only at the moment of making or breaking the current. These are not of tetanic nature, but short and sudden, followed immediately by relaxation, and while the current is passing continuously along the nerve, there are no muscular contractions. These phenomena are influenced by the intensity of the current, the stronger it is the more energetic the contractions, and if it be very powerful, there may be tetanic spasms, not only on making and breaking, but during its passage along the nerve. The muscular movements vary according to the direction of the current so that there are four different contractions:—1. The descending closure contraction; 2. The descending opening contraction; 3. The ascending closure contraction, and 4. The ascending opening contraction. These are further modified in strength by the intensity of the current; and the systematic arrangement of which has given rise to what is termed Pflüger's law of contraction, which is as follows:

	Descending.		Ascending.	
	Make.	Break.	Make.	Break.
Very weak	C.	—	—	—
Weak	C.	—	C.	—
Moderate	C.	C.	C.	C.
Strong	C.	—	C.	C.

These observations were made with both poles of the battery applied to the exposed nerve, in animals. When the polar method of investigation is employed the reactions are somewhat different. When the effects of one pole are eliminated by placing it on a distant or indifferent part of the body, and applying the other to the nerve, we can thus observe the uncomplicated reactions of the latter. In this way also four contractions are produced namely:—1. C.C.C. or cathodal closure contraction; 2. C.O.C. or cathodal opening contraction; 3. A.C.C. or anodal closure contraction; and 4. A.O.C. or anodal opening contraction. Following this method it will be found that different degrees of muscucular contraction result, according to the pole applied to the nerve, as well as to the intensity of the galvanism employed. The cathode always predominates over the anode in its power of inducing functional activity. If a very weak current is used and both poles in succession be placed upon a nerve, and alternately opened and closed, as the current is gradually increased, the first contraction to appear is the C.C.C. As the intensity is slowly augmented the C.C.C. increases in force, and in addition the A.O.C. is devoloped. Further increase more fully demonstrates the C.C.C. and A.O.C., and next appears the A.C.C. Finally a powerful current induces not only C.C.C., A.O.C., and A.C.C., each stronger than the other, according to its order, but ultimately C.O.C. The normal *polar reactions* of the nerve therefore occur in the following order:—1. C.C.C., 2. A.O.C., 3. A.C.C., and 4. C.O.C.

In the human subject the same general laws remain in force, but as here it is impossible to operate upon the exposed nerve we are compelled to influence it through the skin and other tissues. This causes some slight differences in the phenomena, due probably to the diffusion of currents in the body, and to the modifying influence of the resisting media. Practically, therefore, when we apply galvanism to an accessible nerve of the human body, for example the ulnar, we obtain the short sudden contraction of muscle, only at the closing and opening of the current, and in the following order:—1st. C.C.C. 2nd. and 3rd. A.C.C. and A.O.C., these two are of about the same amount, one sometimes being in excess of the other, and *vice versâ*; and 4th. C.O.C. The chief practical fact to be noted is, that in health the C.C.C. exceeds the A.C.C. and the A.O.C. the C.O.C. In the normal condition the galvanic current to nerve does not produce such vigorous contractions as the faradic. The more rapidly it is interrupted the more powerful are the stimulating effects, and when this is very quickly performed there is tetanic spasm as in the case of the induced current, but not to the same extent. The same laws apply to all the nerves of the body that are equally accessible and that are under similar conditions, at the same time it is to be noted that very few of even those superficial, are exactly under the same circumstances in different localities, so that care should be taken in comparing the phenomena in one region with that of another.

Motor points.—The action of electricity on the motor points are precisely similar to those just described, as they are simply branches of the motor nerve trunks. Their stimulation causes contraction of the entire muscle or the larger mass of it.

3. Voluntary Muscle.

The faradic and galvanic currents directly applied to the muscles in health, produce the same phenomena as when the nerves which supply them are similarly treated. The reactions are the same in character, but less vigorous in degree, and, apart from diffusion of the current, only such portions of the muscle contract as are directly stimulated. Hence, the action which follows is due to irritation of the intra-muscular nerve filaments. When the muscle is deprived of its nerve influence by poison or otherwise, leaving its fibres healthy, the reactions are very different. The *faradic* current then applied produces no contraction whatever, no matter how slowly the interruptions may be made. The action of the *galvanic* current to muscle thus deprived of its nerve is augmented, so that a weaker power is required to produce contractions than in the normal state. This demonstrates that the fibre itself is contractile. This increased galvano-muscular excitability is difficult to explain, but is probably due to some change in the nutrition of the muscular structure as a result of absence of nerve influence. In this condition there is contraction not only at closing and opening of the current, but if this be powerful, there is often a slight tetanic spasm during its continuous passage. In healthy muscular fibre, the polar reactions are the same as to the nerve. With a normal nervous supply, the more rapidly the galvanic current is interrupted, the more vigorous is the muscular contraction. When this is cut off the reverse takes place. It is true that the fibre, when healthy, responds to interrupted galvanism up to a certain point (50-60 per second), but the slower the interruptions are made, the more complete are the contractions. Therefore, healthy muscular fibre, when deprived of its nerve influence, contracts more vigorously to slow, and less so to rapid interruptions of the galvanic current, than in the normal condition, and it does not respond to any form of faradism. There is another distinction. When the nerves are intact, the muscular action is sudden, short, and complete; when nerve influence is removed it is delayed, prolonged, and incomplete. Muscular fibre by itself is therefore contractile under the galvanic stimulus, but in a different way than when irritated through the nerve. A more prolonged application, and more abundant quantity of electricity is necessary to produce effects, and these, when arrived at, differ in kind. Hence the induced current of high tension and small quantity causes no results, even when slowly interrupted, but galvanism with its low tension and large quantity, excites contractions, and these are the more vigorous, the more slowly it is interrupted. The same explains the greater response to the closing as compared with the opening of the current.* To all the voluntary muscles of the human body the same laws apply. Practically, however, there are slight differences of degree, the larger a muscle and the coarser its texture, the more powerful is the current required to cause a proportionate amount of contraction. Again, in special parts of the body the skin, fat, and other resisting media vary so greatly as to necessitate different degrees of electricity to penetrate the obstruction before reaching the muscles below.

Relative Excitability of Different Nerves and Muscles.—This question of the different conducting media in the body is a matter of great practical importance. In general terms it may be stated that all the nerves are, if dissected out, equally excitable, subject to the fact that the nearer the centre, the greater the irritability, and conversely, towards the periphery it is somewhat less so. In the same way the muscles, if exposed, would be found nearly all alike, except that they vary slightly in response to faradism, according to the richness of their nervous supply, and to galvanism in proportion to their bulk, and the delicacy of their structure. In the living subject there are differences to be noted. In various localities the conducting media between the electrode and the nerve or muscle, differ so much in thickness, as to cause an unequal distribution in the intensity of the current to the parts below. If one side only is affected, this is of no consequence, as we have then the other and healthy parts with which, under equal circumstances, to compare the diseased tissues. But if corresponding parts of the body are attacked, it is extremely difficult to judge the existence of quantitative changes. It is therefore of great importance to have, if possible, other healthy structures as a standard of comparison. For example, if both lower extremities are affected, leaving the arms normal, we cannot compare one leg with the other healthy one, but for this purpose we can utilise the tissues of the upper limbs. To successfully put this into execution, it is necessary to know the exact comparative irritability of the different nerves and muscles throughout the body.

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* The different actions of the two currents on nerve and muscle may be summed up thus. Faradism is the most powerful stimulant of healthy nerve, and this increases in proportion to the strength of the current, and the rapidity of the interruptions. Galvanism has the same effects, but less vigorous in degree. On healthy muscle deprived of its nerve influence, faradism has no effect, whatever be the number of interruptions, but to galvanism the response is increased, and this in proportion to the strength of the current and the slowness of the interruptions. Thus, practically, faradism acts on nerve alone, while galvanism excites both nerve and muscular fibre, but each in a different manner as above described.

I have made a series of observations on the normal subject with the view of attempting to deduce some definite facts concerning the electric excitability of:—1st, the nerve trunks, 2nd, the motor points, and 3rd, the muscles. The general result of the enquiry is as follows:—

1. *The Motor Nerve Trunks.*—Throughout the body the superficial nerve trunks have been found to be all remarkably uniform in their response to the electric stimulus. At the same time there are marked, if slight, differences, which in making comparisons, it is very important to know. Whether these modifications are due to inherent peculiarities of the nerves themselves, or simply to differences in the conducting media, we need not here discuss, but the opinion may be expressed that it is probably the latter. If a very weak faradic current is in turn applied to all the nerve trunks of the body, and very gradually increased in strength, the first to show any signs of response is the spinal accessory. In short this nerve appears to be the most sensitive to electric irritation in the body. As the current is slowly increased

in intensity, the next nerve which responds, is the branch of the cervical plexus to the levator anguli scapulæ muscle. A further but very slight augmentation brings into action the ulnar. Increased still very slightly, the median, facial, remainder of the cervical plexus, anterior crural, and external popliteal, react, all as nearly as possible being of equal excitability, but varying a little in different individuals. A further increase brings into action the musculo-spiral, and the internal popliteal. In tabular form the following is the order in which the excitability of the various superficial nerve trunks appears to exist.

Spinal Accessory,
Branch to Levator Anguli Scapulæ,
Ulnar,
Median,
Facial,
Cervical Plexus,
Anterior Crural,
External Popliteal,
Musculo-Spiral,
Internal Popliteal.

Although, owing to the deficiency of our apparatus, we have no means of accurately measuring the differences of excitability here indicated, these are in all cases so slight, that if properly learnt by observation and experience in the healthy subject, in practice a comparison can be made between the different nerves in disease. For example, suppose the lower extremities to be paralyzed, we cannot compare one leg with the other, as both are affected, but by a knowledge of the relative irritability of the nerves in the upper and healthy parts of the body, we may arrive at an approximative idea of the truth. Thus, the anterior crural and external popliteal nerves, we know in health are as nearly as possible equal to the median and facial. The internal popliteal is about the same as the musculo-spiral, or somewhat less excitable than the median.

2. *The Motor Points.*—It may be stated in general terms that most of the motor points of a given district are of nearly equal excitability. They vary somewhat in the same, and in different individuals, and only an approximate comparison can be made between them. Like the nerve trunks, they diminish somewhat in irritability at the peripheral as compared with the more central portions of the body. The best general guide is the nearest healthy nerve trunk, the excitability of which is somewhat greater than the motor points in its neighbourhood. For example, a current which produces vigorous contractions when applied to the ulnar nerve, will cause well marked action of all the motor points in front of the forearm, but not quite to the same extent as when the trunk is stimulated.

3. *The Muscles.*—In stimulating the substance of muscle directly, a stronger current is required to cause its contraction, than that sufficient to produce the same result through the medium of its nerve. In different portions of the body, in health, this muscular irritability varies, owing to the fact that some are more richly endowed with nervous supply than others, and hence are more readily stimulated by the induced current. Again, the larger and coarser the fibres of a muscle are, the more intense a continuous current must be used to provoke contraction. Finally, the conducting media, such as the skin, fat, connective tissue, also the state of the integument whether moist or dry, etc., varies in different localities, so as to modify the action of both forms of electricity. The muscles of the upper extremities are more easily stimulated than those of the lower; the flexors of the arms more than

the extensors, and the inner and anterior aspects of the legs, more than the outer and posterior. Those of the trunk, and especially the large muscles of the back and abdomen, are less irritable as a rule than those of the limbs, and the back less than the front of the body.

To sum up the whole question of the relative excitability of nerve trunk, motor point, and muscle, it may be said that no positive special laws can be laid down, as it varies in the same and different individuals. At the same time an attempt has been made to show, that up to a certain point, various localities have a tolerably fixed relation to one another, and and that if we cannot, with scientific and measurable accuracy, form a perfect standard with which to compare different parts of the body, experience and practical knowledge of the facts we possess, furnish us with data which proves useful in diagnosis.

CHAPTER VI.

EXPERIMENTAL RESEARCHES.

THE effects of electricity on healthy nerve and muscle having been seen to be positive, and subject to definite laws, its action on the same structures after injury or destruction, has now to be investigated. The conclusions arrived at have been, for the most part, determined by experiments on the lower animals, and the results of these have been fully confirmed by clinical observations on disease in the human subject. We are mainly indebted to the researches of Duchenne, Erb, Neumann, Ranvier, and others, for our scientific knowledge of the relations which exist between the histological condition of structure, and the functions and electrical reactions of the different tissues.

A. ANATOMICAL CHANGES RESULTING FROM INJURY TO NERVOUS TISSUE.

Spinal Cord.—If the cord is artificially divided at any point, there is paralysis of the body below the section. No anatomical changes, however, ensue, and the nerves and muscles remain healthy. If a portion of the whole thickness of the cord is destroyed, say for an inch or two in length, there would ensue degeneration of the nerves and muscles originating at the injured segment, the nature of which will presently be described. All the tissues derived from below this point would be normal. If the entire cord were artificially destroyed, and the animal lived, there would subsequently ensue complete degeneration of all the nerves and muscles supplied from its entire length. These phenomena indicate that if the spinal cord is injured at the origin of a motor nerve, the latter rapidly loses its healthy structure and functional activity, its nutrition is interfered with, it degenerates, and with it the muscle it supplies. They also point out that so long as a motor nerve is attached to a healthy centre in the cord, even although it may be separated from the brain by disease higher up, and consequently its voluntary function lost, the nerves and muscles retain their healthy structure. Thus, loss of physiological function may be quite independent of histological changes in cord, nerve, or muscle; on the other hand, when these exist, there is often a relation between the two.

In man the same general sequence of events ensues after injury or disease of the cord, although owing to the nature of the lesion, we have rarely opportunities of observing such typical symptoms, as in experiments on animals. When a thin section of the cord is injured, as when divided by a dagger, the voluntary motor power is lost below the stab, but the muscles and nerves do not atrophy or undergo any degeneration. When the injury affects the whole thickness of the the cord for a limited extent, as from pressure of a vertebra, the same symptoms take place, but there is degeneration of the injured portion of the cord, of the nerves derived from it, and of the muscles supplied by them. In the lower part of the body the nutrition remains unimpaired. Finally, when as in myelitis, the entire thickness and length of the cord is diseased, there is wasting and degeneration of all the muscles and nerves of the lower part of the body.

Motor Nerve.—If a motor nerve is divided, there is at once paralysis of the muscles it supplies. Subsequently, pathological changes take place in the structure of both nerve and muscle as a consequence of the injury, and of their being severed from their nutritive centre, the spinal cord. As these histological changes bear an important relation to the electrical conditions, it is necessary that they should be studied. The motor portion of the nerve above the section remains normal, but below it, changes at once begin to take place. Erb thus sums up these anatomical alterations. "Even during the first few days coagulation of the medullary sheath takes place, and it gradually breaks-up into longer or shorter cylindrical masses. These masses become progressively smaller, more rounded, and gradually converted into drops of various sizes, amongst which at the end of the first week, a progressively increasing number of fine fat-granules may be observed. About this period the size of the degenerating fibres has undergone considerable increase, so that they appear broader than usual; the medullary masses and the drops of fat gradually unite, and form larger or smaller irregular heaps, the smaller drops gradually preponderating and giving rise to the appearance of numerous fat-granules distributed through the nerves: after the third or fourth week, there is a very considerable diminution of the medullary and fatty masses, which vanish in great part by absorption, but partly also by becoming converted into a homogeneous uniform mass which fills the still remaining sheath of Schwann, and is traversed by the axis cylinder (Neumann). The degenerating fibres become gradually more slender, and ultimately there only remains a delicate pale band, with irregularly undulating contours, still containing, at certain points, medullary and fat drops, and usually exhibiting a considerable increase in the number of nuclei." The axis cylinder ultimately becomes completely destroyed, but possesses great power of resistance, being preserved in a modified form for a long time after the injury. "Coincidently with these processes of degeneration in the nerve fibres which spread with tolerable rapidity from the centre to the periphery, considerable changes also occur in the neurolemma. There may be seen a remarkable increase and multiplication of the nuclei of the sheath of Schwann in the neurolemma itself, and an extraordinary accumulation of cellular elements. In the course of three or four weeks, the greater number of these assume the character of fusiform cells, coincidently with which there is a progressive hypertrophy of the neurolemma; the external nerve sheath is greatly thickened, strong trabeculæ of connective tissue divide the several fasciculi of nerves from one another, and the hypertrophied connective tissue may be seen to separate the individual fibres. As the process continues, the hypertrophied connective tissue becomes denser, firmer, and fibrous; true cirrhosis of the nerve is established, which is very clearly apparent when transverse sections are made."

Although after complete division of a motor nerve there is entire loss of function, and the train of pathological changes just enumerated, the two ends of the divided nerve may heal, the morbid changes gradually disappear, and the function be completely restored. This process begins at the central segment, by a formation of tissue which extends to the peripheral end of the nerve, and ultimately becomes nerve fibre. The exact method in which this takes place is not known, but this is certain, that the two ends of the divided nerve become joined by nervous tissue capable of transmitting function as before. Whether the recovery is complete or partial, depends on the special circumstances of the case.

Voluntary Muscle.—After division of a nerve, changes also occur in the muscle which bear a close connection to those above enumerated. Atrophy of the muscular fibres, according to Erb, "first begins to be distinctly marked in the course of the second week, steadily advances during the following weeks, and may be easily recognized both in longitudinal and transverse sections, but especially in the latter. In the course of five or six weeks the average breadth of the fibres will be found to have diminished to less than half their normal size. This progresses, the several fibres gradually disappear, and there ultimately remains only the hypertrophied connective tissue. This only takes place after the lapse of many months, and frequently only after several years. In addition to the atrophy, other changes may be observed in the fibres. The transverse striæ become less distinct, less sharply defined, they are more closely approximated and more delicate, though they do not entirely disappear. The fibres frequently appear slightly cloudy, though they never, in the earlier stages, present distinct granular or fatty degeneration. At this period the muscle-nuclei exhibit notable multiplication which commences in the course of the second week, and soon after advances to such a height that where previously a single nucleus might be found, there are now collections of from six to eight, which especially in the atrophied muscles, are crowded together, and are much more readily visible without the employment of reagents than in healthy muscles. Lastly, a chemical change may be demonstrated in the contractile substance which is rendered evident by a tendency on the part of the fibres, increasing with the duration of the paralysis, to undergo after injury or death, the peculiar change known under the name of "waxy degeneration."

The modifications in the interstitial connective tissue commence at about the beginning of the second week with a moderate accumulation of cell elements, so that in many places the appearance is presented of granulation-tissue having been formed between the muscles. This is particularly well marked around the blood vessels and the degenerated nerve trunks, and is everywhere easily discoverable for several weeks. From the sixth week onwards the cells gradually disappear, after first becoming for the most part fusiform, and changing into the dense, wavy connective tissue which is rapidly forming. This hypertrophy of the interstitial connective tissue can also be recognized at as early a period as the second week, from which time it steadily increases week by week, new material gradually assuming the form of dense, wavy bands of connective tissue of considerable breadth, which penetrate the muscles, and separate the several fibres from each other by strong septa. The muscles are thereby rendered denser and firmer, and the newly-formed tissue subsequently undergoes cicatricial retraction."

If regeneration of nerve takes place, these morbid changes in the muscle may gradually clear away. This, however, is always a very slow, and generally imperfect process, owing to the extensive hypertrophy of the connective tissue, constituting a true cirrhosis of the muscle. In those cases which do not recover, the hypertrophied connective tissue becomes more dense, and there is total atrophy and disappearance of the muscular fibre, so that after some years the muscles are converted into flattened cords of connective tissue.

The explanation of all these phenomena, which appears to be most probable, and which is supported by the facts of the present enquiry is, that these degenerate changes in nerve and muscle are due to the separation of the tissues from the central nervous system. Here, there would seem to exist those elements which preside over the nutrition of these structures which undergo changes when their influence is removed. Whether there are special trophic tracts, and where these lie, are questions not yet practically demonstrated.

B. ELECTRICAL REACTIONS AFTER INJURY TO NERVOUS TISSUES.

Accompanying these anatomical changes, there are corresponding alterations in function, and in electrical reactions. The extent and nature of the last, enable us to judge with great accuracy the condition and stage of the former; indeed, it is the correspondence between them, and the deductions which can thus be formed, that constitute the art of electro-diagnosis.

Spinal Cord.—After simple division of the cord, the electrical reactions of all the nerves and muscles remain normal. When a portion of the entire thickness of the cord is injured or diseased, the current applied to the part itself would produce no effect. The nerves derived from it, as well as the muscles they supply, would exhibit the characteristic changes of degeneration, which will be presently described. All the structures below this point would be normal. Destruction of the entire cord would be followed by the same degenerative changes in all the nerves and muscles it supplies.

Motor Nerve.—When a motor nerve is divided, and the series of histological changes, above described, induced, the electrical conditions of both nerve and muscle deviate from the healthy type, and the alterations in each must be specially studied. Immediately after the section of the nerve, there is sometimes slight increase of electric response to both currents, when applied to the peripheral portion, which, however, only lasts a day or two. This is due to excess of excitability, as a result of irritation from the injury. After this there is a continuous quantitative diminution with both currents, without qualitative changes, a stronger power being necessary to cause the former amount of muscular contractions. This shows diminished functional activity of nerve accompanying organic changes in structure. This impaired response rapidly advances so that in from the seventh to the twelfth day, the excitability of the nerve to both currents becomes completely abolished, this loss of action spreading from the cut surface of the nerve to its periphery. This remains permanent, unless regeneration takes place, in which case the normal contractions slowly return in proportion to the renewal of tissue, and to about the same extent with both currents. The improvement begins in the same direction as the disease followed, namely, from the centre to the periphery. For a long time the response to both currents remains below the normal standard, even after voluntary motion has quite recovered. This fact indicates, that although the nerve has sufficiently recovered to convey voluntary impressions of motion, owing to the recent changes in structure it has not yet completely attained its electric excitability.

When the nerve is partially injured, or bruised only, the electrical reactions are not so complete, but bear a relation to the severity of the anatomical changes.

Voluntary Muscle.—The reactions to muscle are more complicated, and differ with the two currents, the action of which must be considered separately.

Faradism—With this the action is exactly similar to that of nerve, namely,—rapid diminution ending in complete extinction in about twelve days, at the end of which time direct irritation of the muscle with the induced current produces no muscular contractions. This shows that the peripheral branches of the nerve, as well as its trunk, are functionally as well as structurally altered. The return reactions to muscle, in cases which recover, are the same as those to nerve, only somewhat more tardy in appearance.

Galvanism.—The reactions with this are very different. On being applied directly to the muscle, for the first week there is progressive diminution of response, sometimes preceeded by slight exaltation. At the end of this time, a gradual increase of reaction is developed, which, towards the close of the second week, may exceed the normal condition. This indicates the effects of removal of the nerve influence, the muscular fibre itself being as yet structurally healthy. Soon afterwards, qualitative alterations or a change in the natural order of the law of contractions, develope themselves. This is exactly reversed, the anodal closure contraction being increased so as to equal or exceed the cathodal closure contraction (A.C.C. = C.C.C. or A.C.C. > C.C.C.) and the cathodal opening, equals or surpasses the anodal opening contraction (C.O.C. = A.O.C. or C.O.C. > A.O.C. The nature of the contraction also differs. In place of being as in health, immediate, and short, it is sluggish and prolonged, and often there is a state of muscular tonus which remains while the current is passing. This sequence of events has been termed by Erb the "Reaction of Degeneration," which is a convenient expression indicating that series of electrical phenomena, associated with degeneration of muscle. At certain stages, the opening contractions altogether disappear, and this in proportion as the slowness of the contractions increase to the closure of the current. This condition lasts from three to eight weeks or more, indicating alteration of muscular fibre, without absolute destruction of it. After this, there is a gradual diminution of response to the galvanic current, although the qualitative changes remain, with the slow and prolonged nature of the contraction. This points to organic disintegration of the muscular substance, and this is in proportion to the amount of electrical impairment of response. This may so increase, that in cases which do not recover, it is finally completely lost, the anodal closure contraction being the last to be demonstrated. Then we may conclude that the muscle is totally destroyed. If the muscle recovers, the galvanic reaction is slowly re-established, but remains for a long time below the normal standard, after voluntary power has returned, and later even than the effects of faradism on the nerve. So that after the response of nerve to the induced current is normal, that of muscle to the continuous may remain diminished. This is evidence, that the regeneration of nerve and voluntary motion, is in advance of that of muscle, which is a slower process. The reaction of galvanism to muscle is therefore independent of that of faradism to nerve, so that we may have the latter producing healthy contractions when stimulated indirectly, with normal voluntary motion, and at the same time with the former diminished response, and even slight qualitative changes when applied directly to the muscle. Such would suggest that while both nerve and muscle were practically healthy, the latter from its late thickening and induration constitutes a bad conducting medium for the electricity to reach and act upon its substance.

Such then is the sequence of anatomical changes, which occur both in nerve and muscle, after artificial section of the former, and also the series of electrical phenomena which ensues. These bear a marked relation to one another, so that a careful comparison of the preceding considerations will enable the observer from the electrical conditions, to arrive at an exact knowledge of the histological state of either nerve or muscle. A knowledge of this, as will subsequently be shown, is of the greatest importance in the the diagnosis of many nervous diseases. The diminution or loss of electric excitability to nerve, indicates its degeneration, and the stage in proportion which it has reached. The extinction of the faradic current to muscle, does not prove muscular degeneration, but loss of excitability of the nervous filaments in its substance. The increase to the galvanic current shows the fibres to be essentially healthy, but their nutrition altered through being deprived of nerve influence, and the qualitative changes, indicate degenerative modifications of its structure. The subsequent diminution of the galvanic irritability, is evidence of atrophy of the fibres, and its total loss is proof of the complete destruction of the muscle.

The following table attempts to show the relation which exists between the anatomical changes in nerve and muscle, and the electrical reactions. A case of serious injury of nerve is taken as an example.

Anatomical State of Nerve and Muscle.	*Electrical Reactions.*
Before injury. Nerve and muscle normal.	Before injury. Electrical reactions normal.
1*st week* after injury. *Nerve.* Coagulation, breaking up of medullary sheath into granules and fat globules. *Muscle.* No marked change.	1*st week* after injury. *Nerve.* Faradism and galvanism, great diminution. *Muscle.* Faradism, great diminution, galvanism, slight diminution.
2nd to 4th week. *Nerve.* Continued degeneration, extensive fatty metamorphosis. *Muscle.* Commencing atrophy of fibres.	*2nd to 4th week.* *Nerve.* Faradism and galvanism, total loss of reaction. *Muscle.* Faradism, total loss of reaction. Galvanism, gradual increase of response C.C.C. > A.C.C., but latter increased.
4th to 10th week. *Nerve.* Continued degeneration, diminution of medullary and fatty masses which are absorbed, hypertrophy of neurolemma. *Muscle.* Atrophy continues, diameter of fibres diminished by absorption. Striæ obliterated. Multiplication of nuclei. Increase of connective tissue.	*4th to 10th week.* *Nerve.* Total loss of response to faradism and galvanism. *Muscle.* Total loss to faradism. To galvanism response still high above normal but begins to diminish. Contraction slow and tonic, A.C.C. = C.C.C., or A.C.C. > C.C.C.

10th to 30th week. Nerve. Tubes completely degenerated, increase of nuclei, masses of fat and granules, axis cylinder resists longest, hypertrophied connective tissue in abundance, true cirrhosis of nerve. *Muscle.* Atrophy progresses, granular and fatty degeneration, disappearance of fibres, hypertrophied connective tissue.	*10th to 30th week. Nerve.* Total loss to faradism and galvanism. *Muscle.* Total loss to faradism. To galvanism response has gradually fallen to about normal level. Contraction slow and tonic. A.C.C. = C.C.C., or A.C.C. > C.C.C.
30th to 40th week. Nerve. Regeneration begins, absorption of degenerated matter, new formation of nerve tissue. *Muscle.* Continues as before. Cirrhosis.	*30th to 40th week. Nerve.* Gradual return of response to both currents. *Muscle.* Faradism, no response. Galvanism falls below normal. A.C.C. = C.C.C., or A.C.C. > C.C.C.
40th to 55th week. Nerve. Regeneration continues. *Muscle.* Begins to regenerate.	*40th to 55th week. Nerve.* Continued increase of response to both currents, but both still below normal. *Muscle.* Response to faradism begins. Galvanism still falling.
After 55th week. Regeneration progresses slowly in both *nerve* and *muscle* to complete recovery. Connective tissue of muscle long remaining thickened.	*After 55th week.* Reaction to both *nerve* and *muscle* gradually improve, but remain a long time below normal after voluntary motion has completely returned.

CHAPTER VII.

ELECTRICAL REACTIONS IN DISEASE.

WE have seen, that after mechanical injury to a motor nerve, a well defined series of pathological changes ensue, in both nerve and muscle. The same sequence of events is found to take place in many diseases of the nervous system. It has been also shown, that these anatomical alterations are accompanied by characteristic electrical reactions, the one bearing a constant relation to the other. It is, therefore, evident, that a careful comparative study of these physical states, must lead to very important information concerning the nature of disease. In the present enquiry, we shall have to deal mainly with modifications of motility, and more particularly with paralysis. In this condition the electrical reactions vary in its different forms, and may be classified as follows:—

1. *Normal Reactions in Paralysis.*—With loss of voluntary motion, the responses resulting from the irritation of both currents, to nerve and muscle, may be normal, or practically little changed. This indicates that, although movements are arrested, the structure of nerve and muscle is healthy. This occurs in all paralyses of *cerebral* origin, the explanation of which will be understood from a consideration of the hypothesis subsequently to be advanced, namely, that serious degenerative changes only take place, when there is either disorganisation of the trophic centres of the spinal cord, or when the influence of these is cut off from the tissues by disease or injury of any portion of the motor tract. These normal reactions also occur in many *spinal* paralyses, indeed, in all those in which the grey matter of the cord is not in-

volved. Even in paraplegia, as a result of this, the electrical reactions of the lower limbs may be normal. This shows that the portion of the cord, from which the nerves to the lower extremities take their origin, is healthy. Careful examination of the muscles higher up, would probably end in the discovery of some point where abnormal electrical reactions were found, from the extent of which we would infer the limits of the lesion in the grey matter. The same may exist in certain stages of *peripheral* paralysis, especially those of a slight and temporary character, indicating, that although the affection is sufficient to cause abeyance of voluntary motion, it is not so advanced as to induce such organic change as leads to abnormal electrical reactions. Finally, the whole class of so-called *functional* paralyses are as a rule accompanied by negative phenomena. For example, in a chronic case of hysterical paraplegia, the responses to the faradic and galvanic currents would be everywhere normal to both nerve and muscle.

2. *Quantitative Changes in Paralysis.*—These consist of simple increase, or diminution, of electrical response, without the reaction of degeneration or other qualitative changes.

(a.) Simple Increase, is occasionally seen in a variety of different forms of paralysis. It is usually of slight degree and of temporary duration. It is sometimes present in the affected limbs, resulting from *cerebral* disease, and especially in its early stages. It occurs in hemiplegia following hæmorrhage, embolus, and other acute diseases of the brain, and is due, either to the presence of an irritating lesion, or to the inhibitory influence of the cerebral centre being removed from the peripheral tissues. Therefore, simple increase of electro-excitability, slight, uniform, and temporary, at the outset of the disease often occurs in cerebral disorders, and if the increase be considerable there is probably an irritating lesion.

In certain forms of *spinal* disease this quantitative increase may also be found. In almost all acute and inflammatory affections, such as meningitis and myelitis, this may exist at their onset, but as a rule is only temporary, and is due to increased excitability of the tissues as a result of the morbid process. It usually disappears with the progress of the disease, as it becomes chronic. In any irritating lesion of the cord this may likewise be observed, but is generally of a transitory nature. In certain chronic disorders it exists, and more especially in the early stages of degeneration of the posterior, and antero-lateral columns, as in locomotor ataxy and lateral sclerosis, and in the latter disease, it may be of a tolerably permanent character. Even in the incipient stages of chronic disease of the grey matter of the cord, this increase of response may occasionally be observed, as in progressive muscular atrophy, infantile paralysis, etc., but is always slight in degree and temporary in duration. This condition is probably due to the excitability of the nervous structures being increased by irritation of the disease in the cord. In cases of paraplegia, the whole thickness of the cord may be destroyed to a limited extent, producing complete paralysis of the lower part of the body, and yet the electrical reactions may be there quantitatively increased. This is due, partly to irritation, but is chiefly the result of the inhibitory influence of the brain being removed from the peripheral parts, the tracts to and from which, probably lie in the lateral columns. Increase of electrical response is occasionally observed in the very early stages of *peripheral* paralysis, in which it is slight and temporary, and is the result of the irritating lesion. This increase is also seen in *functional* paralyses, and in cases of weakness from general debility; and is explained by depression of the nervous centres, depriving the nerve and muscle of their normal inhibitory influence. Increase of response with galvanism, and diminution with faradism, to muscle, is almost always associated with qualitative changes, and indicates serious disease of the nerve, with commencing alteration of muscle.

Another explanation of the increased electric excitability may be, that the disease has modified the conducting media of the affected parts. Atrophy of fat, skin, or ohter tissues, may, by diminishing the resistance, enable the current to reach the structures below more readily than in health, and thus cause an apparent increase of action. In other ways also, that we cannot explain, the unhealthy condition may augment the readiness of response. On this subject we have little definite information, but it must not be lost sight of that this is a possible explanation of hyper-excitability to the electric stimulus.

In some anomalous forms of paralysis to which we apply the term "hysterical," there is remarkable irritability and exaggeration of all the reflex acts. These are so exalted, that when an electrical current is applied to a nerve or its branches, it excites a series of reactions never seen in health. Instead of the muscular contractions being limited to the tissues directly stimulated, there is vigorous action of the neighbouring, and even of distant parts. Sometimes the muscles of the opposite limb are put into functional activity. Benedickt states that he has observed this in a case of progressive muscular atrophy. Personally I have noticed these phenomena on several occasions, but only in those forms of paralysis which from other circumstances had been diagnosed as hysterical. Beard and Rockwell consider this to be the result of organic disease of the cord. This will of course depend upon the definition of so called functional disease and what the pathologist understands by the word "organic." Under any circumstances it is clear evidence of some abnormal hyper-excitability of the nervous system, and of some local condition of the grey matter of the cord, quite apart from cerebral and mere volitional imperfections.

b. Simple Diminution. 1st Nerve.—The response of both currents to the nerve may diminish to complete abolition, without necessarily being accompanied with qualitative changes. To a moderate extent this may be present in all very chronic forms of paralysis from whatever source, and is the result, partly of function being so long in abeyance, and to simple atrophy, and partly to secondary degeneration in the nerves themselves. In paralysis from *cerebral* disease which has existed many years, there is generally slight quantitative diminution of response in the affected limbs, as compared with those of the healthy side, but this never exists to a great extent, even in the most advanced cases. The same takes place, and for the same reason, in chronic *spinal* paralysis. If the anterior cornua are diseased, there are in addition, qualitative changes. Finally, simple diminution in response appears in almost all cases of *peripheral* paralysis.

Simple diminution of response in all these cases indicates, that while the function of the motor nerve is impaired, and its structure altered, its degeneration is not complete, and the extent of this may be judged from the amount of the electrical reaction. Care must be taken not to confound the diminished action to nerve, with a possible primary atrophy of muscle.

2nd Muscle.—Diminution or loss of response to the *faradic* stimulus applied directly to muscle, indicates impairment or destruction of the intra-muscular nerves, not necessarily of the fibres themselves. This usually occurs coincidentally with disease of the nerve trunks, and under the same conditions. Diminution or loss to the *galvanic* current, is generally accompanied by qualitative changes, but by itself indicates serious destruction of muscular tissue.

3. *Qualitative Changes in Paralysis.*—This implies that the electrical responses to nerve and muscle have undergone changes in quality and character, in addition to alterations in quantity and degree. The former never exists without the latter, and the two together constitute the reaction of degeneration. In *cerebral* paralysis this is never seen, except in those unusual cases, when a tumour of the brain, by mechanical pressure, causes disease of a peripheral nerve, with the usual degenerative sequence of events. This, however, is not a true cerebral paralysis. In certain forms of *spinal* paralysis the reaction of degeneration is found in its full extent, namely, complete loss of response of nerve to both currents, loss of response of muscle to faradism, increased action of muscle to galvanism, with inverted polar reactions. This is seen in diseases of the cord, in which the multipolar cells of the anterior cornua of the grey matter are degenerated, as in extensive myelitis, and infantile paralysis. This reaction is never met with in degenerations of any other portion of the cord, and is consequently absent when the posterior or antero-lateral columns alone are involved, as in locomotor ataxy, and lateral sclerosis. In *peripheral* paralysis, the reaction of degeneration is present in its most typical form, and is met with in all severe injuries or diseases of the motor nerve trunks. It is therefore found in surgical injuries to nerves, and in all those morbid conditions, rheumatic and otherwise, which seriously involve their structure. This condition is also seen in certain affections, the origin and nature of which are as yet not thoroughly understood, such as lead palsy, but if not demonstrated, the general symptoms as well as the electrical reactions, enable us to suspect the seat of lesion.

The complete series of changes just described, indicates serious disease of both nerve and muscle. There are, however, modifications from the typical reaction of degeneration, by no means uncommon, and very important in diagnosis. 1st. The increase of galvanic response is frequently absent, all the other signs being present. The explanation of this is not certain, but it is probably due to the fact that, in chronic disease, the changes in nerve and muscle proceed slowly together, so that by the time the influence of the nerve is totally lost, the excitability of the muscular fibre has partially diminished. This seems all the more likely as we find that the increase is always best marked in paralysis which is sudden and complete. 2nd. The response to the *nerve* may remain normal throughout its whole extent, and produce healthy reactions when stimulated with both currents, the *muscle* irritated directly with faradism also being followed by normal actions; but with galvanism, indicating the usual degenerative reactions, as in progressive muscular atrophy, amyotrophic lateral sclerosis, etc. This indicates that while the nutrition of the nerve is healthy, that of the muscle is diseased. 3rd. Conditions arise in which the nerve trunk is found impaired to the action of both currents, but each, when applied directly to the muscle, is followed by normal reactions. This points to partial disease of the nerve trunk, its peripheral intra-muscular branches, and the muscle itself remaining healthy. This is seen in the early stages of rheumatic neuritis, or traumatic injury of nerve. 4th. Both currents applied to the nerve trunk fail to produce any response, with faradism to muscle no reaction, but with galvanism to the latter, normal or increased reactions. This indicates that the nerve is diseased throughout its entire length, including the peripheral filaments, and that the muscle is healthy, which is sometimes seen in the earlier stages of nerve trunk disease, and in acute affections of the anterior cornua of the cord. 5th. There may exist a state in which both currents applied to the trunk of a nerve, produce normal contractions, faradism direct to muscle, no response, and galvanism to the same, healthy action. This is evidence of normal nerve trunk and muscular fibre, but disease of the intra-muscular nervous branches, and is found in cases of temporary paralysis from cold, etc. This phenomenon also shows that the healthy nerve trunk, when stimulated, is capable of transmitting its motor influence to the muscle through its diseased peripheral branches. 6th. When irritation of the nerve trunks by both currents cause normal contractions, faradism direct to muscle no response, and galvanism to the same, all the signs of reaction of degeneration, we conclude that the trunk of the nerve is healthy, and that there is degeneration of muscle with its intra-muscular nerves. This may sometimes be seen in lead palsy. 7th. With nerve either healthy or diseased, if muscle shows quantitative diminution to galvanism, with or without qualitative changes, it indicates serious degeneration of the muscular substance, as seen in advanced infantile paralysis and progressive muscular atrophy. 8th. Lastly, complete abolition of response with both currents, to nerve and muscle, indicates entire destruction of these two structures, as seen in the late stages of polio-myelitis anterior, lead poisoning, and peripheral paralysis.

4. *Effects of Interrupting the Currents in Paralysis. Faradism.*—In health, as has already been pointed out, the more rapidly the faradic current is interrupted, the more powerful is the stimulus to a motor nerve. In disease it is exactly the reverse, as when there is nervous degeneration, the slower the interruptions, the more vigorous the muscular contractions, and *vice versâ*. At certain stages of disease there may

be no response whatever to irritation of a nerve with rapid interruptions, while this may exist when they are very slow. The practical knowledge we arrive at from varying the interruptions of the faradic-current is, that in proportion as the nerve fails to respond to these when rapid, so may we conclude that its excitability is diminished. If it still reacts to slow, but not to quick interruptions, we may assume that its irritability, although impaired, is not altogether destroyed. The same follows when the induced current is applied directly to muscle, from which we infer the condition of the intramuscular nerves.

Galvanism.—In disease, the result of the interrupted continuous current when applied to nerve, is the same as that just described as occurring after faradism, namely, the more advanced the degeneration, the less capable it is of responding to rapid interruptions. When the nerve is so altered in structure as to deprive the muscle of all nervous influence, the reactions on the latter are different. We have already seen that under these circumstances where the fibres remain healthy there is tetanic spasm when interrupted galvanism is applied to them, but the energy of this is in proportion with the slowness of the interruptions, hence the more rapid they are, even in health, the less active the result. When the fibres are diseased, this power of response to the interrupted continuous current is diminished, so that as the degeneration advances, the muscle only responds to very slow contractions. Thus, in our inquiry, if a muscle reacts to very rapid galvanic interruptions, we may infer that its structure and nerve supply is normal, and in proportion as it fails to respond, so are these degenerated. If the nerve trunk does not, but the muscle itself reacts to a moderately interrupted current, we may conclude that, while there is alteration in the structure of the former, the latter is not materially involved. If the muscle only contracts with slow interruptions, it is evidence of considerable modification in its nutrition, and finally, if it does not contract with even the slowest interruptions of a powerful current, we may conclude that total destruction has ensued.

I have observed on several occasions in diseased muscle, that rapidly interrupted galvanism produced a sudden contraction, immediately followed by relaxation, although the current still continued to pass; in short there was no tetanus. I do not know how this is to be explained, or what morbid state it exactly represents. It would seem to indicate that in advanced muscular degeneration, without complete disorganization, the shock of interrupted galvanism produces a contraction, but that the muscle, owing to disease, has lost its tonicity, and capacity to maintain a tetanic spasm.

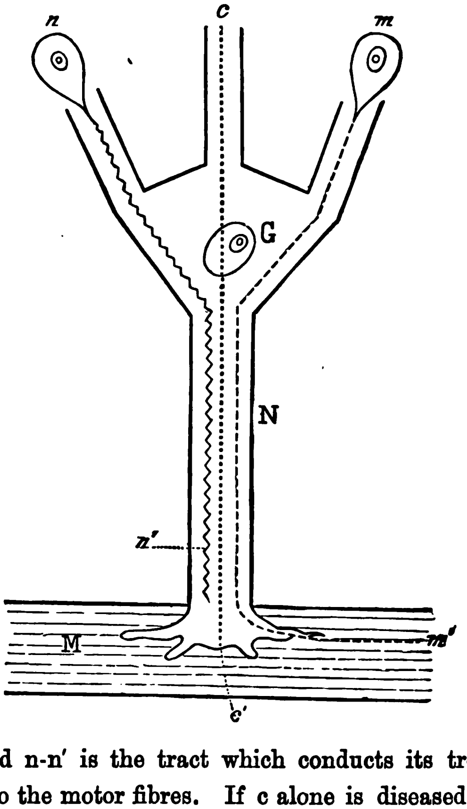
THEORY OF ELECTRICAL REACTIONS IN DISEASE.

We have seen, in paralysis arising from diseases of different localities, and involving different structures, that although loss of voluntary motion is a common symptom of all, the electrical reactions greatly vary, and that, as we shall find, according to the tissues affected. In some these are normal, in some there are only quantitative changes, and in others there are qualitative alterations in various degrees and character. This last, or the reaction of degeneration, is never found in paralysis from brain disease, or in those affections of the spinal cord in which the white columns alone are degenerated. It is met with only when there is a lesion of the grey matter of the cord, or when there is serious injury or disease of the peripheral nerves. It is therefore evident that destruction of the cerebral tissues, or of the white columns of the cord, do not in any way affect the nutrition of nerve and muscle, while if the grey matter of the latter is disorganized, or its influence severed from the muscle, there is atrophy with modified electrical reactions. This fact combined with clinical observations, seem to indicate that in the centres there are various separate tracts for conveying nervous influences, whether of sensory, motor, or trophic character, that these run different courses, and that one or more of them may be specially diseased. The most plausible hypothesis to explain this, although not anatomically demonstrated, and that which seems to accord best with known facts, presumes, that in the multipolar cells of the anterior cornua of the grey matter of the cord, are situated those elements which preside over the nutrition of both nerve and muscle. When this portion of the nervous centre is completely destroyed, there is invariably alteration in their structure, as seen in severe myelitis and infantile paralysis. That these nutritive centres are distinct from the sensory or motor tracts is evident from the fact that there may be a loss of both sensation and motion, without necessary alteration in the structure of either nerve or muscle, as is observed in paralysis from disease of the brain or white columns of the cord; and conversely there may be degeneration of tissues, without either paralysis of motion or sensation, as is seen in progressive muscular atrophy. It would also appear that the trophic centres themselves may be further subdivided into special channels supplying particular tissues, as in the anterior cornua there not only exist elements influencing the nutrition of nerve and muscle, but these apparently are distinct from one another, running a different course, and capable of being independently diseased. This is indicated by the fact that in certain partial degenerations of the grey matter of the cord, the muscular substance alone atrophies, while the nerve tissues remain healthy, as in progressive muscular atrophy; and in others the nerve may be altered, and the muscle continue normal, as in the early stages of polio-myelitis anterior. In disease of the anterior cornua, why certain of their trophic cells should become functionally inactive, leaving others normal, we do not know, nor has an explanation as yet been anatomically demonstrated. The clinical and pathological fact remains, that in diseases of the anterior cornua, in some the nerve only is degenerated, in some the muscle alone, and in others both of these are altered in structure. The practical point to be observed is, that in paralysis from disease of the spinal cord, if degeneration of either nerve, or muscle, or both exist, we may conclude that the seat of the lesion is in the ganglionic cells of its anterior cornua, and on the contrary, if these structures are normal, it may be inferred that this portion of of this spinal centre is healthy.

The same explanation is applicable to the phenomena of the reaction of degeneration, which follows injury or disease of peripheral nerve. In this case the tracts conveying nutritive and motor influences to the nerve and muscle are severed by the lesion, and the connection between the centres and the tissues are broken. Hence the completeness of the paralysis and of the degenerative and electrical changes following peripheral nerve affections, as compared with those following cord disease, in which some of the elements may escape destruction.

All these phenomena have been ingeniously portrayed by Erb, and the accompanying diagram (fig. 5), slightly modified from his, places this hypothesis in so clear a light, as to be readily understood. G is a large multipolar ganglionic cell in the anterior cornua of the cord. N a peripheral nerve trunk supplying M, a muscle. c is the motor conductor from the brain, which lies in the lateral columns of the cord; this continues through the ganglionic point G to c′. m is the central trophic apparatus for the muscle. The tract m-m′ represents the trophic conduction emanating from the apparatus, and somewhere (probably at G) uniting with the motor tract. n is the central trophic apparatus for the motor nerve, and n-n′ is the tract which conducts its trophic influences to the motor fibres. If c alone is diseased, there is paralysis without atrophy of nerve or muscle, and normal electrical reactions as in cerebral diseases, and lateral sclerosis. If m alone is diseased there is atrophy of muscle,

FIG. 5.



without paralysis or nerve affection, and the electrical reactions demonstrate normal conditions to nerve, with quantitative and qualitative alterations of muscle, as seen in progressive muscular atrophy and bulbar paralysis. If n alone is diseased, the nerve is degenerated, and the muscle remains healthy. The electrical responses are lost to nerve, and galvanism is normal to muscle, as seen in the early stages of infantile paralysis. If c-m are both diseased, there is paralysis with muscular atrophy, the electrical reactions indicate healthy nerve and diseased muscle, as in amyotrophic lateral sclerosis. If c-n are diseased, there is paralysis with degeneration of nerve, and healthy muscle. If m-n are diseased, there is degeneration of both nerve and muscle. The same ensues with paralysis if c-n-m are all affected together, or G by itself is destroyed, as seen in myelitis transversa, or polio-myelitis anterior.

When N is entirely diseased, including the tracts c′-n′-m′, there is complete loss of voluntary motion, with degeneration of nerve and muscle, with corresponding electrical reactions, or the severe form of peripheral paralysis. If c′-m′ or c′-n′ are degenerated, in the one case there is paralysis with atrophy of muscle, and in the other paralysis with alteration in nerve, or the middle forms of peripheral paralysis. If the tract c′ alone is involved, there is loss of voluntary motion, with healthy nerve and muscle, and normal electrical reactions, or the mild form of peripheral paralysis.

It is to be remembered that the preceding statements are purely hypothetical and diagrammatic, and although they appear to be the most plausible explanations of the clinical facts, it must be admitted that they have not been actually demonstrated.

CHAPTER VIII.

ELECTRICAL REACTIONS IN SPECIAL PARALYSES, ILLUSTRATED BY CASES.

I. PARALYSIS FROM DISEASE OF THE BRAIN.

IN paralysis, as a result of disease of the brain, the electrical reactions of both nerve and muscle are as a rule normal. However long the loss of motion may have existed, the contractility of the affected muscles is the same as in health. Although this is the general law, it is subject to certain limitations. If the local injury or disease produces irritation of the centres, the excitability of the nerves and muscles is sometimes thereby augmented; and there is in consequence simple quantitative *increase* of response to the electrical stimulus, which is observed chiefly at the onset of the disease. Another reason for this increased reaction in paralysis from destruction of cerebral tissue, is, that as a consequence the inhibitory influence of the brain upon the spinal cord and nerves is removed, and thus motor activity is augmented below the seat of lesion. Again, this may be the result of a modification of the resisting media caused by the disease, due to atrophy of the intervening tissues, especially of the skin and fat. This may induce an apparent excess of action to the same strength of current on the affected, as compared with the healthy side. In certain other cases, especially those of a very chronic nature, there may be simple quantitative *diminution* of electrical response, but this never exists to a great extent. It is the result of disuse of the muscles bringing about simple atrophy of their substance, and consequently slight diminution in the vigour of their contractions. It may also be due to secondary anatomical changes in the spinal cord and nerves, which are accompanied by modifications in their excitability. Certain cerebral diseases, such as tumours, abscesses, etc., may, by pressure on the cranial nerves cause their degeneration and corresponding electrical changes, but such cases are in reality peripheral paralyses, although originating in a lesion of the brain. In short, for practical purposes it may be stated, that in paralysis from brain disease, the electrical reactions to the affected nerves and muscles are normal, or only exhibit slight quantitative, and never qualitative modifications. This fact by itself is of great importance in diagnosis.

A. Paralysis from Disease of the Brain. Electrical Reactions Normal.

Case I.—*Hemiplegia of three years standing, probably hæmorrhagic. Electrical reactions normal.* E. M., æt. 60, female, housewife. With the exception of headaches, the patient was quite well till three years ago, when her husband died. Soon afterwards, having gone to bed one night in her usual health, next morning her right arm and leg were found partially paralysed. From this she in some degree recovered. Six months afterwards, while lifting a heavy weight, her left arm suddenly became completely useless. This after a time improved, but imperfectly. A year ago the right side became gradually weaker, and this has increased up to the present time.

On examination, the patient is a fairly healthy looking woman. Her head has a tendency to lean towards the left side. There is slight indistinctness of speech, but no aphasia. The lower part of the right side of the face is partially paralysed. The special senses are normal. The tongue is protruded slightly to the left, and its movements are sluggish. Both arms are very weak in all their movements, and she cannot reach her head with either hand. There are no contractures. She is very lame in the right leg, and drags the toes turned outwards along the ground. There is no atrophy of the muscles.

Electrical Reactions.—These are normal with both currents applied to nerves and muscles.

Case II.—*Paralysis of right arm of four years duration, the result of cerebral disease. Electrical Reactions normal.* W. G., æt. 55, male, tailor. The patient states that he was in good health till about four years ago, when for the first time he noticed weakness of the right arm and hand. This very gradually increased, so that in two years he was obliged to give up his work. Since then the paresis has continued to augment. He thinks that recently the right leg has been slightly weak, and that with the arm it sometimes shakes. Lately, he fancies his speech and eyesight have been affected.

At present the patient is a perfectly healthy and intelligent man. There is slight external strabismus of the right eye, and both pupils are dilated and sluggish. The mouth when opened, is slightly drawn to the left. Speech is not affected. Sensibility everywhere normal. There is paralysis of the right arm, but this is not complete. Most of the movements can be performed but very slowly and feebly. He cannot overcome the weight of his arm in raising it towards his head, the movements of the joints are feeble and the grasp of the hand is almost nil. There is no atrophy, rigidity, or contracture of the limb, but there is a slight tremor of the entire right upper extremity and hand, which is increased by emotion, and attempts at suppressing it. The remainder of the body is healthy, except that the patient states he thinks the right leg is slightly weaker than formerly.

The only objective symptom there to be discovered, is very slight tremor. The reflexes on both sides are equal and normal.

Electrical Reactions.—To the nerves and muscles of all the limbs, the paralysed one included, the reactions to faradism and galvanism, are normal, and equal on both sides.

B. PARALYSIS FROM DISEASE OF THE BRAIN. ELECTRICAL REACTIONS QUANTITATIVELY INCREASED.

CASE III.—*Hemiplegia of four months standing, probably hæmorrhagic. Electrical reactions, quantitatively increased.* F. S., æt. 22, male, fishmonger. The patient states that he was quite well till four months ago. One day, without apparent cause, and while engaged at his ordinary work, he fell down unconscious, and had "a fit." On recovering from this he was paralysed on the left side, but was able to walk home with assistance. Next morning the entire left side was completely motionless. Since then, the loss of power has continued, but has considerably improved.

At present, the patient is a healthy looking man. At rest, the face is drawn to the right side, and on movement, it is markedly deficient in action on the left. Speech is slightly indistinct, but there is no aphasia. All the movements of the left upper extremity are very feeble and imperfect, the grasp of the hand being almost nil. All the muscles are in a state of rigidity and contracture, which can be overcome by gentle passive motion. There is no atrophy of the limbs. The patient walks lame, and drags the left leg, which is stiff and rigid, owing.to muscular contracture. The heart is normal.

Electrical reactions.—Application of both currents to the nerve trunks of the left side, indicate marked increase of muscular contractions as compared to those of the right side, and a weak current which produces slight reactions on the left, does not do so on the right. To the muscles, the contractions are slightly more vigorous on the paralysed than on the healthy side. There are no qualitative changes.

C. PARALYSIS FROM DISEASE OF THE BRAIN. ELECTRICAL REACTIONS QUANTITATIVELY DIMINISHED.

CASE IV.—*Hemiplegia of fourteen years standing, probably embolic. Electrical reactions, quantitatively diminished.* M. C., æt. 35, Female, S. Barmaid. The patient was quite well till fourteen years ago. One morning on waking the patient found she was speechless and paralysed on the right side. She was taken to a hospital where she remained a month, at the end of which time her speech had completely returned, and the paralysis had much improved. A year afterwards the patient had an attack of a similar nature and her right side has been weak ever since.

At present the general health is good and there is no heart disease. The patient walks very lame with the right leg, which she swings, and the muscles of which are stiff and rigid. The movements of the right arm are very limited, partly owing to the advanced state of contracture in the limb. All the joints are firmly flexed, and the skin is cold and livid.

Electrical Reactions.—Faradism applied to the nerve trunks and muscles of the right, shows the responses to be universally diminished as compared with the left side, but not to a great extent. *Galvanism* to both nerves and muscles of the affected limbs indicates slight quantitative diminution, without qualitative changes.

D. PARALYSIS FROM DISEASE OF THE BRAIN. ELECTRICAL REACTIONS NORMAL TO MOST OF THE NERVES AND MUSCLES. REACTION OF DEGENERATION TO CERTAIN NERVES AND MUSCLES AS A RESULT OF MECHANICAL PRESSURE.

CASE V.—*Right hemiplegia probably the result of cerebral abscess. Electrical reactions to paralysed side normal. Left facial paralysis with reaction of degeneration to muscles.* J. G., æt. 64, male, mason. The patient has suffered for many years from diabetes, but with this exception has been in good health till about a year ago. At this time he had a fall on the head, and was severely wounded over the left parietal bone. Portions of this necrosed and kept up an open sore, which only healed a few weeks ago. Three weeks ago he was one day suddenly seized with a feeling of stiffness in the left side of his face, and shortly afterwards it was noticed that this was partially paralysed, and that the features were drawn towards the right. He also experienced severe pains in the head, and acute ear-ache on the left side. These symptoms have continued since.

At present the diabetes exists as formerly. The left side of the face is completely paralysed with all the usual symptoms, the features drawn towards the right, inability to close the left eye, embarrassed speech, collection of food in the cheeks, etc. Sensibility of both sides of the face normal.

Electrical Reactions.—Faradism applied to both nerve and muscle on the left side, produce no contractions. There is also no response with galvanism to the nerve trunks. This current directly to the muscles causes more vigorous contractions on the diseased than on the healthy side, they are slow and tonic, and the A.C.C.>C.C.C.

The severe pain in the head, with giddiness, and paralysis of the face continued, without any affection of the limb Since the accident, the sight of the right eye has been in paired, (he has long been blind of the left eye), and he h become deaf in the left ear. The patient also says that h has experienced some difficulty in articulating and in swa lowing. He has no aphasia or defects in intelligence. I this condition the patient remained for about thirteen month when one day, without obvious cause, he was suddenly seize with giddiness, loss of speech, and paralysis of the right sid including the face, without unconsciousness. When see four days afterwards, he was very lame with the right le the movements of the right arm were extremely feeble, the was partial paralysis of the right side of the face, and th speech was thick and mumbling, but not aphasic, the mov ments of the tongue were very sluggish, and the intelligen seemed unaffected. Four months afterwards the hemiplegi was in much the same condition.

Electrical Reactions.—The nerve trunks and muscles of th entire right side showed normal reactions to both current including the face. On the left side of the face, which also paralysed, the reaction of degeneration still remains i the muscles, but now the responses to galvanism are muc diminished in intensity.

II. PARALYSIS FROM DISEASE OF THE SPINAL CORD.

In the numerous forms of paralysis, resulting from disea of the spinal cord, the electrical reactions vary in the differe types, and their modifications depend entirely on the exte and seat of the central lesion, indeed, it is the result of careful examination of their character and distribution, whic constitutes so important an aid to diagnosis. It may be la down as a broad general law, that in paralysis from disea of the cord, if the grey matter is not involved, there are no nutritive alterations, and the electrical reactions are *normal.* Hence, if the anterior, lateral, or posterior columns only are degenerated, even throughout their whole extent, the responses of both nerve and muscle to the faradic and galvanic currents show no material alterations.

There are, however, certain limitations to this rule. If there be acute inflammation of the cord or its membranes, we find simple quantitative *increase* of electrical responses. This indicates a general nerve excitability without actual degeneration, due to the irritative lesion of the centre. The same applies to any disease of the cord, chronic or otherwise, which causes hyper-excitability of the nervous system. This simple increase may also occur when there is limited and complete disease of the cord leaving its lower part healthy. Owing to the inhibitory action of the brain being thus cut off, the parts supplied from the normal centres below, exhibit in consequence increased excitability.

Again, in all very chronic cases of paralysis from disease of the cord of any kind, there may be simple quantitative *diminution* of electrical response due either to atrophy from long continued disuse of the muscles, or to secondary degeneration in the motor nerves.

When the grey matter of the cord is seriously diseased there is almost always interference with the nutrition of nerve and muscle, and consequently abnormal electrical reactions. This is more especially the case when the large multipolar cells of the anterior cornua are degenerated. In such instances there are the typical reactions of degeneration. If the whole length and thickness of the cord is diseased, there would be atrophy of all the muscles and nerves derived from it, and hence there would be universal abnormal electrical reactions. In the case when a portion only, say an inch or two, was diseased throughout, having healthy structure above and below, there is paralysis of all the parts supplied from and below the lesion. In those nerves which originate in that segment of the cord actually diseased, there would be degeneration, also in the muscles they supply, and consequently abnormal electrical reactions; but the muscles and nerves attached to the healthy centre below, would be normal both in structure and response to both currents, or possibly augmented quantitatively. In such a case there would be a band of abnormal electrical changes, corresponding with the amount of cord disease, with healthy tissues above and below. Finally, very limited, but complete transverse disease might exist, producing paralysis of the parts below, but the electrical reactions remaining normal, as the disease, being very local, does not seriously involve any of the motor roots. Any of the above conditions may exist alone, but in practice they are often complicated, one or more being present at the same time. The destructive lesion may not be complete, it may invade several centres, or parts of centres, it may be associated with irritative disease, in all of which cases the electrical reactions may be imperfect, or mixed, so much so, that in many instances, it may be almost impossible to obtain definite or reliable data. This, indeed, constitutes the great difficulty in the practice of electro-diagnosis.

A. Paralysis from Disease of the Spinal Cord, Electrical Reactions Normal.

Locomotor Ataxy.

In the large majority of cases of locomotor ataxy, the electrical reactions are normal. In some, especially in their early stages, these are quantitatively increased, but this condition is always slight and temporary. In others of a very chronic nature, there is said to be quantitative diminution to a limited extent, due probably to simple functional disuse of the muscles. This last I have never seen, although I have had opportunities of observing several cases of more than fifteen years standing, and one of thirty years duration, in which the reactions were perfectly normal. There are never any qualitative changes.

Case VI.—*Locomotor ataxy of four years duration. Electrical reactions normal.* W. R., æt. 35, male, engineer. The patient states that he was in good health till about four years ago, and that he never acquired syphilis. Without apparent cause he was then seized with darting pains all over his body, which were very frequent and severe. These continued for two years without any other symptoms, after which it was noticed that his legs became weak and unsteady, which symptoms have gradually increased up to the present time.

On examination, the patient appears anæmic, but is otherwise healthy looking. His walking powers are very uncertain, and he cannot move about without assistance. He has the characteristic ataxic gait, throws his legs about, cannot co-ordinate his movements, stamps his feet, has to keep his eyes on his legs otherwise he falls down, and in short, he suffers from all the usual symptoms of a tolerably advanced case of the disease. Although individual movements are energetic, the patient soon becomes fatigued on exertion. There is unsteadiness in the movements of both arms and hands, and his writing and other accustomed acts are greatly impaired although the muscular power remains vigorous. The patellar tendon reflexes are completely abolished. There is no muscular wasting. The sensibility of the legs is diminished to touch and pain, and he does not feel the ground distinctly. There is no affection of the bladder, but the patient has slight incontinence of urine. He still complains of the lancinating pains in his limbs. The sight is slightly impaired, but the other senses are normal. Sexual power abolished.

Electrical Reactions.—A careful examination of all the nerves and muscles of the body with both currents, failed to discover anything abnormal.

Case VII.—*Incipient Locomotor Ataxy of nine months duration. Electrical Responses quantitatively increased.* S.S., æt. 50, male, soldier. The patient states that he has been a perfectly healthy man all his life. He was twenty one years in a cavalry regiment, and was ten years in India, but during all that time he lived a steady life and enjoyed good health. He never had syphilis. About nine months ago he experienced for the first time, shooting pains in his legs, and soon after noticed that these were weak. These symptoms have continued since.

At present the patient has good general health. His intellect and special senses are normal. He is perfectly healthy in all respects except in his lower extremities. He complains of frequent attacks of lancinating pains in the legs, there is slight incontinence of urine and total loss of sexual power. He walks fairly well and can accomplish several miles a day. The gait is somewhat unsteady, and jerking, there is hesitation on turning, and in short it presents all the symptoms of a slight form of ataxy. With his feet together he oscillates, more especially in the dark or if his eyes are closed. There is no numbness or loss of tactile sensibility but he feels as if he were walking on "feathers." The plantar reflexes are exaggerated and the patient has frequent involuntary jerkings of the limbs. The tendon reflexes are completely abolished.

Electrical Reactions.—The same current which produces very slight muscular contractions to the ulnar and median nerves causes very vigorous ones to the anterior crural and popliteal nerves. The muscles to the faradic current respond more freely in the lower than in the upper extremities. No qualitative changes.

SPASTIC PARALYSIS.

In this disease the electrical reactions in the large majority of cases are normal. In the early stages there is generally slight increase of the excitability of nerve and muscle, and this may continue for a considerable time after the disease has developed. In very chronic cases there is sometimes quantitative diminution but never to a great extent. There are no qualitative changes.

CASE VIII.—*Spastic Paralysis of one year's duration. Almost complete loss of voluntary motion. Electrical Reactions normal.* L. W. æt. 38, female, shopkeeper. The patient states that she was a perfectly healthy woman till eleven months ago. Then her husband died, and she had much trouble with her children. About this time she got soaked with rain and snow, and on the following day she felt generally unwell. About a week afterwards she experienced tingling in the feet, and a feeling of a tight cord round her waist, but there were no feverish symptoms or pain in the back. Shortly afterwards the legs became weak and this increased so that in three weeks she could not walk. A month or two afterwards contracture began in the muscles, and the legs were drawn up, and there were often spasmodic twitchings of the limbs.

At present the general health is good. The sensibility is everywhere normal. There is no pain or tenderness of the spine. The upper part of the body is in every way normal. The lower limbs are powerfully and permanently contracted so that the knees nearly reach the abdomen and the heels the thighs. The flexors are hard and tense. The joints cannot be extended and the attempt to do so causes great pain in the muscles and back. There is very slight movement of the toes and ankle joints, otherwise there is complete paralysis. There is no actual wasting although the muscles are spare and thin. No bladder or rectal troubles. There are frequent involuntary spasms of the lower limbs. Cutaneous reflex actions strongly marked but, tendon reflexes could not be ascertained owing to the contracture.

Electrical Reactions.—To all the nerve trunks and muscles with both currents the reactions were normal.

CASE IX.—*Spastic Paralysis of eighteen months duration, Electrical reactions quantitatively increased.* F. P., æt. 28, male, soldier. The patient states that he was quite well till five years ago when he contracted syphilis. From this he recovered and remained healthy till eighteen months ago. Then being in India and without apparent cause he experienced weakness in his legs. This rapidly increased so that in about a weak he was unable to walk. He had no illness or pains of any kind. During the succeeding few months he somewhat improved and his condition became much the same as it is at the present time.

On examination the patient is found a healthy looking man, robust in every respect except his lower extremities. There is much weakness of the legs. The patient walks with some difficulty with the aid of two sticks. The gait is a characteristic spastic one, stiff, slightly springing, walking on the toes which are dragged along the ground, etc. There is considerable rigidity of all the muscles which can be overcome with passive motion. Plantar and other cutaneous reflexes much exaggerated. Knee jerk phenomena in great excess, and ankle clonus well marked on both sides. There are frequent involuntary movements of the limbs, which are drawn up in bed. The sensibility is normal. There are no bladder, rectal, trophic, or vaso-motor alterations. The remainder of the body is normal.

Electrical Reactions.—A weak Faradic current which produced a minimum amount of contraction when applied to the nerves and muscles of the head and upper limbs, caused very vigorous action to those of the lower extremities. This was very distinctly marked. A weak faradic current applied to any part of one of the legs induced tetanic spasm more or less throughout the whole limb and frequently caused the phenomenon of ankle clonus. To the galvanic current the same excitability of reaction was present, but without qualitative change.

Case X.—*Spastic Paralysis of twelve years duration. Electrical reactions quantitatively diminished.* A. F., æt. 40, male, carpenter. The patient states that he was a healthy man till twelve years ago. At this time after sleeping in a damp bed he noticed that his legs became weak, and stiff, and this increased so that in three weeks he could not walk. From this, in a hospital, he recovered in about a month, and some weeks afterwards was able to resume his usual work. He remained well for about two years. About this time there very gradually appeared a weakness and stiffness of the right leg. This very slowly increased and he walked lame with that extremity. This advanced and affected the other limb so that two years afterwards he had to give up his occupation. This condition very gradually increased till about three years ago, by which time he had completely lost the use of his legs and was unable to move them in the slightest degree, and this has continued with slight fluctuations ever since.

At present the general health of the patient is perfectly good and he is normal in every respect above the waist. There is almost total loss of motion in the lower extremities the only movements being very slight flexion of the knees.

There is great stiffness and rigidity of all the muscles of the legs and thighs, and the joints are permanently partially flexed, a condition only to be overcome with considerable force. There is slight difficulty in making water and the bowels are constipated, otherwise the bladder and rectum are healthy. There are marked fibrillary tremors of the muscles of the lower limbs. The patellar tendon reflexes are exaggerated and tetanic in character. There is a tendency to ankle clonus, but no plantar reflexes can be elicited. The skin of the thighs is somewhat cold and slightly mottled. There are no trophic changes and the limbs are well nourished. Sensibility is everywhere normal. There are no abnormalities of the spinal column.

Electrical Reactions.—Faradism when applied to the nerve trunks and muscles of both lower extremities, show considerable diminution of response, a strong current being required to produce contractions. When this is powerful the actions are vigorous and otherwise normal. With galvanism there is the same condition, and no qualitative changes.

MULTIPLE SCLEROSIS.

In this disease trophic changes in the large majority of cases are absent and consequently the electrical reactions are normal. In the early stages there is generally quantitative increase of response which may remain for a considerable period after the onset of the disease. In very advanced cases there is said to be slight quantitative diminution but I have not met with an instance. If the grey matter becomes involved, the nutrition would be modified and the electrical reactions would be changed in proportion.

Case XI.—*Cerebro-spinal multiple Sclerosis of seven years duration. Electrical reactions normal.* J. S. æt. 46, male, sawyer. The patient states that he was in fairly good health till seven years ago. About this time without obvious cause his present complaint began. This increased very slowly and insidiously. He has suffered much from pain in the head, he is very nervous, weak and shaky, and has been afflicted with dullness and loss of memory. He has not been able to do any work for two years.

At present the patient is a depressed, pale and delicate looking man. He answers questions with fair intelligence but is dull and apethetic. He complains of constant giddiness and severe pain in the head. He talks in a slow and deliberate manner. His gait is weak, unsteady and embarrassed, but there is no actual dragging of the feet or ataxy. The movements of the arms and hands are slow and feeble. The face is drawn slightly to the left side. The sight is weak but the other senses are normal. There are no bladder or rectal troubles. No atrophy of muscles. There is a constant tremor of the whole body including the head which is increased when attention is directed to it, or attempts made at its suppression. All the reflexes are greatly exaggerated especially those of the patellar tendons, and there is ankle clonus on both sides. Sensibility is slightly blunted especially on the left side.

Electrical Reactions—A careful examination of all the nerve trunks and muscles proved them to be universally normal.

Case XII.—*Multiple Spinal Sclerosis of two months duration. Electrical reactions quantitatively increased.* M. C., æt. 43, female, housewife. The patient states that she was quite well till two months ago. One morning without apparent cause she was seized with shivering, headache, and feverish symptoms. Next day these continued, and in addition there was pain in the back and twitchings in the legs. During the next few days all these symptoms increased and being unable to walk about from weakness in her limbs, she was compelled to go to bed. She remained there for five weeks during which time the pain in the back was severe, there was much weakness of all her extremities, and a slight feeling of numbness in the legs with muscular startings. She then entered the hospital where she has been for the last fortnight.

At present the general health of the patient is good. She now does not complain of any pain in the back or elsewhere. The intelligence, sensibility, and special senses are normal. The spine is in appearance healthy and there is no tenderness; the arms and hands are weak, but movements can be performed fairly well. The grasp of the hands is feeble. She cannot perform actions so well as formerly, but can sew, knit, &c.; the hand-writing is very shaky and characteristic. The legs are very weak, so that the patient walks with great difficulty; the gait is feeble, shuffling, and uncertain, but there is no ataxy or spasm. There is a very distinct tremor of all the extremities most marked in the hands, which is increased on emotion or on action, and cannot be controlled for a moment. Cutaneous reflex movements are increased, and the patellar tendon phenomena much exaggerated. No ankle clonus. There is no atrophy or rigidity of muscles. Sensibility everywhere normal.

Electrical Reactions.—Both currents applied to the nerve trunks of the upper extremities produce vigorous and apparently healthy contractions, and to the muscles the same but not quite so well marked. The same strength applied to the anterior crural, external and internal popliteal nerves, causes much more powerful action. When applied to the muscles there are vigorous contractions, but not so much so as when the nerves are irritated. No qualitative changes.

PARALYSIS AGITANS.

In this disease, however great the paresis may be, the nutrition of the nerves and muscles, and consequently the electrical reactions remain normal.

CASE XIII.—*Paralysis Agitans of two years standing. Considerable paresis of left side. Electrical Reactions normal.* M. H., æt. 50, female, housewife. The patient states that she has been a nervous delicate person all her life, but never suffered from any definite complaint till two years ago; she then was subjected to great anxiety about business affairs, in the midst of which began a tremor of her limbs, which has continued to increase till the present time, and this has been accompanied, especially on the left side, with weakness.

At present the patient is a somewhat frail and delicate looking woman, but her organs are healthy and her general health fairly good. There is a tremor all over the body, well marked on the left side, comparatively less on the right, and very slight in the head. This movement is much increased by emotion, excitement and so on, and is not increased on voluntary motion, on the contrary, to a certain extent, it can be controlled by the will for a few moments but not entirely. During sleep there is no tremor. Sensibility normal. The patient generally is weak and feeble, but on the left side this is much more marked than on the right. The patient never had attacks of any kind and her intellectual faculties and special senses are intact.

Electrical Reactions. These are normal and equal on both sides to nerve and muscle with both currents.

B. PARALYSIS FROM DISEASE OF THE SPINAL CORD. ELECTRICAL REACTIONS QUANTITATIVELY INCREASED.

This condition is met with under a variety of circumstances and in many different diseases. It indicates increased nervous irritability, and is rarely of high degree or prolonged in duration. It is found in most acute affections of the cord, such as meningitis, myelitis, &c. It occurs in the early stages of many chronic complaints unaccompanied with qualitative changes such as Locomotor Ataxy (Case VII), Spastic Paralysis (Case IX), Multiple Sclerosis (Case XII), and others. Even when the grey matter is the starting point of the lesion, at the very early stages this increase of electrical response to the nerves is sometimes seen, as in Progressive Muscular Atrophy (Case XV). It is also said to occur in Infantile Paralysis and Lead Poisoning, but I have never met with a case of either. This phenomenon in short demonstrates that, while the structure of the nerve is not anatomically degenerated, its tissue is in a state of hyper-excitability. It specially occurs in those cases where the cord remaining healthy below is cut off from cerebral influence by limited disease or pressure above, of which the following is an example.

CASE XIV.—*Acute curvature of spine. Paraplegia of two years duration. Electrical reactions quantitatively increased in the paralysed limbs.* E. B., æt. 6, female. The patient was in fairly good health till two years ago, when she fell off a chair and hurt her back. She was unwell for some time after this, and soon weakness in her legs was noticed. This continued slowly to increase till three months ago, when it was observed for the first time that her spine protruded. Prior to this she had been treated in hospital with a plaster of Paris jacket, and after a time her powers of locomotion greatly improved. Three months ago the paresis of the legs became so advanced that she was unable to walk, and this has continued ever since.

At present the patient is a pale delicate looking child, but with fair general health. There is no pain in the back, but when she sits up for any time she says it aches. In the upper dorsal region there is an acute curvature of the spine, occupying from the 2nd to the 7th dorsal vertebra. There are no cerebral symptoms, and the patient is intelligent. The arms are normal. Both legs are extremely weak, and the patient cannot stand. When lying on the back the legs can be moved, but slowly and feebly, both sides being about equal. The lower extremities as well as the rest of the body are thin and spare, but there is no actual or special atrophy. It is difficult to ascertain the amount of sensibility, but it is not entirely lost. There is no rigidity or marked vaso-motor disturbances. Cutaneous and tendon reflexes are greatly exaggerated in the lower extremities. The other organs and functions are normal.

Electrical Reactions.—To the nerve trunks of the lower limbs with both currents, the responses are very vigorous; to feeble currents, and more so than to the upper extremities. Applied directly to the muscles, there are apparently normal reactions, and no qualitative changes.

C. PARALYSIS FROM DISEASE OF THE CORD. ELECTRICAL REACTIONS QUANTITATIVELY DIMINISHED.

Simple quantitative diminution of response may occur in all forms of paralysis from disease of the cord, but except when the grey matter is involved, only at their latest stages. This is due partly to functional inactivity from prolonged disuse of the muscles, and partly to secondary degenerative changes in the motor nerve tracts. Examples of this are seen in advanced cases of Spastic Paralysis (Case X.), Myelitis (Case XXIX.), etc. In chronic diseases from lesion of the grey matter, this diminution in electrical response also ensues, but is accompanied by qualitative changes, as in the late stages of Progressive Muscular Atrophy (Case XIX.), Infantile Paralysis (Case XXVI.), etc.

D. Paralysis from Disease of the Spinal Cord. Electrical Reactions demonstrating Degeneration of Muscle, with Healthy Nerve.

Progressive Muscular Atrophy.

It may be stated in general terms that in this disease the *induced* current applied to *nerve* always causes healthy electrical reactions. In the early stages of the affection the responses are sometimes increased, but never to a great extent, or of long duration, as they cease before there is any loss of voluntary motion. This is due to increased irritability of the nerve. In advanced stages of the disease there may be slight diminution of response due to secondary changes in the motor fibres, and this is most marked at the periphery, so that the nearer the centre the nerve is stimulated the more marked the muscular contraction. Faradism applied directly to *muscle*, produces contractions exactly in proportion to the amount of its bulk, and to the vigour of its voluntary power. There is no real diminution of farado-muscular contractility, as the nerves in this disease are healthy. In the same ratio that the muscular fibres atrophy, so is the voluntary power weakened, and response to the induced current diminished. This decrease of action may be more apparent than real, owing to the development of fat which interferes with electrical conduction. As the nerve remains normal, any loss of response to faradism is due to deficiency in the muscle, so that from the amount of contraction we may infer the extent of active fibre which remains.

To the *nerve* trunks *galvanism* gives analogous results to faradism. To it the responses remain for a long time normal, with increased reactions at first, and only at very advanced periods of the disease is there slight quantitative diminution in action. Applied directly to *muscle*, the responses are normal or slightly increased for a considerable period, but their force gradually diminishes in proportion to the atrophy of the fibre and the loss of voluntary motion. As the disease further advances, a powerful continuous, will always induce stronger contractions than a strong induced, current; and after this last has failed altogether in effect, the former may be followed by slight response. This may be further augmented by the rapid reversion of the current. Accompanying these quantitative changes are qualitative alterations. The A.C.C. gradually increases in force, and as the disease advances equals, and sometimes exceeds, the C.C.C. Occasionally, but very rarely, the C.O.C. is found increased. The contractions are slow and prolonged only in the very late stages, when the peripheral nerves are impaired. These conditions point to severe degenerative changes in the muscular fibre. In proportion to the amount of quantitative galvano-muscular excitability which remains, and the qualitative conditions which exist, may we infer the extent and character of the anatomical changes in the muscle. As the nerves throughout are healthy, care has to be taken to distinguish between the effects of the current on their filaments and on the muscular fibres themselves, and to eliminate the responses of the former. Again, it is to be remembered that in progressive muscular atrophy some portions of the same muscle may be healthy, and others diseased, in which case, the reactions of the first are liable to be confounded with the responses to the second. Finally, in very advanced cases with total loss of response to faradism, there may remain feeble reactions to galvanism, indicating that although the degeneration of fibre is very extensive, it is not complete. If there is no response to either form of powerful current, we may infer that the muscle is totally destroyed.

CASE XV.—*Incipient Progressive Muscular Atrophy of five weeks duration. Loss of voluntary Power. Hyper-excitability of nerve. Commencing degeneration of muscle.* F. C., æt. 44, male, paper maker. The patient states that he was quite well till about five weeks ago. About this time without apparent cause he began to experience pain in the left shoulder and upper arm, and soon afterwards he noticed weakness in that extremity. These symptoms have continued since.

At present the patient is otherwise a healthy man. He complains of very severe shooting pains throughout the left shoulder and arm. All the movements of this limb can be performed correctly but are weak and feeble in degree. He can with great difficulty raise his hand above his head. The flexion of the arm is readily overcome, the movements of the hand and fingers are imperfect, and the grasp of the hand extremely weak. The left deltoid is distinctly atrophied. The left upper arm is markedly smaller than the right, being one inch less in girth at the thickest part, and its muscles are soft and flabby. The left forearm is half an inch less in girth than the right, but no special atrophy is there observable. The patient has not noticed anything wrong with the right arm or hand.

Electrical Reactions.—Faradism applied to the median, ulnar, and musculo-spiral nerves produce distinctly more vigorous contractions in the left, as compared to the right side. The same occurs but not so marked when it is directly applied to the muscles. Galvanism to the muscles of the left arm produce vigorous contractions C.C.C. > A.C.C., but the latter is very distinctly increased so as nearly to equal the C.C.C. On testing the muscles of the right arm they appear to be healthy in every respect, except that the A.C.C. is much more marked than normal, and as compared with the muscles of the lower extremities.

CASE XVI.—*Early stage of general Progressive muscular atrophy of six months duration. Nerves healthy. Commencing degeneration of muscles.* E. B. æt. 35, male, labourer. The patient states that he was a healthy man until about six months ago, when he was seized with attacks of vomiting and pains in the head. This continued for many weeks but he ultimately recovered. He never however, attained his former vigour, but remained weak and languid. This muscular debility has continued since and latterly he has noticed that the left arm is smaller than the right. There is no history of syphilis, but he has been a very hard liver.

At present the patient is a very pale unhealthy looking man. On examination he is suffering only from general debility as his more urgent symptoms have passed away. The movements of all the limbs seem to be well performed and it is difficult to discover actual paresis of any special muscle as the patient generally is not robust. There is no marked atrophy, but the left upper extremity is smaller, softer and more flabby than the right, the former measuring at its thickest part 10¾ inches and the latter 11⅞ inches. The legs are weak and the patient walks in a shaky and unsteady manner but without any special abnormal gait. There is no tremor, and the sensibility is everywhere normal. The knee jerk phenomenon is exaggerated, but the plantar reflex is diminished. The limbs are thin but no muscles are especially wasted.

Electrical Reactions.—Both currents applied to the nerve trunks throughout the body seem to be followed by normal reactions. So also is faradism to the muscles. *Galvanism* to nearly all the muscles of the upper extremities indicate abnormal changes. On the left side to a moderate current the contractions are vigorous. To the triceps the A.C.C. is nearly double the extent of the C.C.C. To the biceps the A.C.C. = C.C.C. To the Supinator Longus the C.C.C. > A.C.C., but the latter is much increased. To the extensor Carpi Radialis Longior and Brevior, the A.C.C. > C.C.C. To the Extensor Communis Digitorum, the C.C.C. > A.C.C., the latter slightly increased. The Extensor Carpi Ulnaris and Extensor Longus Pollicis are normal. So also are the flexors of the forearm. To the small muscles of the hand the A. C. C. is increased otherwise normal. On the right side all the muscles are normal except the Extensor Carpi Radialis Longior in which the contractions are much more marked than in the healthy muscles and the A.C.C. = C.C.C. To the thenar muscles the A.C.C. > C.C.C. The hypothenar muscles are normal. Rapidly interrupted galvanism causes apparently healthy contractions in all the muscles.

In some of the muscles of the lower extremities there are traces of qualitative change, but of slight extent.

Case XVII.—*Progressive Muscular Atrophy of two and a half years duration. Great loss of voluntary motion, nerves healthy, muscles moderately diseased.* J. S., æt. 45, male, labourer. The patient states that he was quite well till about two and a half years ago. About this time without apparent cause he noticed that his right hand was weak, and this continued very slowly to increase for some months, after which the condition he thinks has become stationary. Six months ago the left hand was affected in a similar manner, and this also has gradually progressed. Accompanying the weakness the arms have become thin.

At present the patient is a healthy looking man, and complains only of weakness in his hands which prevents his working. The movements at the shoulder joints can all be performed without difficulty, so also those of the forearm on the upper arm. The movements of the wrists and fingers are very feeble and imperfect, and the patient has great difficulty in extending them. The grasp of the hands is almost imperceptible. Both deltoids are distinctly wasted especially the left. The other muscles of the shoulder although generally spare cannot be said to be specially atrophied. The muscles of both forearms and hands are considerably wasted, especially the extensors of the hands and fingers, and chiefly those on the right side. The small muscles of the hand are greatly atrophied. The remainder of the body is normal.

Electrical Reactions.—Both currents applied to the nerve trunks of the upper extremities, produce perfectly healthy muscular contractions, except that the extension of the fingers to direct stimulation of the musculo-spiral nerve is imperfect, but all the other muscles supplied by the nerve act fairly well. Faradism applied directly to the muscles of the right arm produce fair contractions even to the affected ones, except the extensors of the hand, especially on the ulnar side, and that of the thumb and fore-finger in which the response is diminished. Also in the common extensors of the fingers the response is greatly diminished. The flexors are normal. In the left arm the radial and ulnar extensors act moderately. There is very little response to the Extensor Communis Digitorum, and extensor of the thumb. The flexors all act vigorously and some more markedly than on the right side. Galvanism applied to the anterior portions of the deltoids induce good contractions, and A.C.C. = C.C.C. At the remainder of the muscle the contraction to the same current is not quite so well marked, and the C.C.C. > A.C.C., but the latter is increased. To the muscles of the upper arm and flexors of the forearm the responses are normal. To the extensors of the hand there are good contractions the C.C.C. > A.C.C., the latter being increased. In the common extensors of fingers the response to galvanism is much diminished, the A.C.C. = C.C.C.

Case XVIII.– *Progressive Muscular Atrophy of four years duration. Almost total loss of voluntary power. Nerve trunks healthy. Muscle completely diseased.* J. L., æt. 33, male, servant. The patient states that he was in good health till four years ago. About this time he received a blow on the back. Three months after this he experienced weakness in the arms and hands which has continued ever since, and has been accompanied by wasting of the muscles of the hand.

At present the patient is a healthy looking man, all his functions and organs being normal. The movements of both upper extremities are generally somewhat weak, but otherwise normal. The grasp of the hand is extremely feeble, the movements of the fingers are limited, and those of the thumb greatly embarrassed. Both hands are similarly affected, the right being the most advanced. There is great atrophy of the small muscles of the thumb.

Electrical Reactions.—Faradism applied to the nerve trunks produce normal contractions. Directly to the muscles, there are healthy reactions in all, except those of the thenar region in which there is no response whatever. Galvanism applied to the muscles of the forearm cause normal contractions, except that the A.C.C. is somewhat increased. The strongest current to the thenar regions cause no muscular contractions.

CASE XIX.—*Progressive Muscular Atrophy of five years duration. Complete loss of voluntary motion. Nerve trunks shewing diminished reactions. Muscles completely degenerated.* R. W., æt. 62, male, labourer. The patient states that he was a healthy man till five years ago. About this time without obvious cause, he began to suffer from weakness of the right hand. This came on very gradually and was soon accompanied by wasting of the muscles, which slowly increased and spread over the entire limb. A year afterwards the same condition appeared in the other arm, and followed an almost similar course. About eighteen months ago there appeared weakness in the legs, which has gradually increased up to the present date.

On examination the patient is found in good general health and perfectly intelligent. The face and head are normal. The right arm is throughout perfectly immovable with the exception of slight extension of the little finger. There is no stiffness or rigidity, all the joints being lax and abnormally mobile. The muscles of the entire limb, including the shoulder, have undergone a remarkable degree of atrophy. The deltoid, muscles of the upper arm, and extensors of the hand and fingers having completely disappeared. The flexors in front of the arm are only partially destroyed. The left upper extremity is in precisely the same condition, only there is a slight action of the biceps muscle. Most of the muscles of the neck and trunk are very markedly wasted, especially those on the anterior aspect of the thorax. Both lower extremities are thin, the muscles of the calves of the legs are soft and flabby, and the extensors of the foot are greatly atrophied. The patient can walk but with great difficulty, and his gait is shuffling and unsteady. Sensibility is everywhere normal. The cutaneous and tendon reflexes are everywhere much exaggerated. The patient complains of no pain or uneasiness and with the exception of the remarkable loss of motility, is in good general health.

Electrical Reactions.—These, in character, are the same in all the affected muscles of the body, only differing in degree according to the amount of atrophy. As this is most marked in the upper extremities, these are taken as an example. Both are in the same condition. *Faradism* applied to the median and ulnar nerves produces fairly vigorous contractions with a strong current, but evidently diminished as compared to normal. The musculo-spiral, when irritated, causes vigorous extension of the little finger and no other action on the other extensors. Powerful currents to the deltoid, triceps, biceps, and all the extensors of the forearm, except that of the little finger on the right side, fail to induce any contraction whatever. Strong currents to the flexors of the hand and fingers cause moderate reactions. *Galvanism* applied to the nerve trunks produce the same effects as faradism. To the extensors of the left hand and fingers, there are absolutely no contractions whatever to the strongest current, and on the right side only the faintest trace with A.C.C. To the flexors of both forearms, there are moderate contractions with a strong current, C.C.C. > A.C.C., but the latter in creased. The same to the supinators. To the right biceps and triceps moderate contractions with a strong current, A.C.C. > C.C.C. To the same on the other side, a very powerful current causes a very slight action, and only with the A.C.C. In the lower limbs and trunk the reactions are the same in kind but not so marked in degree.

PSEUDO-HYPERTROPHIC SPINAL PARALYSIS.

In this disease, *faradism*, when applied to the *nerve* trunks, causes normal contractions till a late stage in the affection. In very chronic conditions there is diminished excitability owing to secondary degeneration of the peripheral nerves, but even then a strong current will always cause contractions while there is any muscular substance left to react. In any case, the results by indirect stimulation are always much more vigorous than by direct, owing to the resistance of the non-conducting matter which has accumulated in the muscle. Faradism applied to *muscle* always exhibits diminution of response, and more than would be accounted for by the actual loss of tissue. This is explained by the presence of a large amount of non-contractile and badly conducting matter, in the shape of fat and connective tissue, causing resistance to the passage of the current. This diminution exists in every degree according to the anatomical condition, and may end in total abolition, indicating entire destruction of muscle.

When *galvanism* is applied to the *nerve* trunks it produces normal contractions till an advanced period of the disease, after which there may be slight quantitative diminution of response, owing to the causes explained above, but it is rarely to the same extent as occurs with the induced current. According to Erb, there is what is called the "Break reaction." This consists of weakening of the anodal *opening* contraction although the current is increased to a considerable extent, but as its strength is further augmented, at a certain point the A.O.C. appears. This is said to show that the conductivity of the nerve is diminished, and its excitability increased, thus causing a break in the series of reactions at the point when the increased efforts of the current are neutralized by the increased resistance. I myself have never seen this phenomenon exactly as here described. Galvanism directly to *muscle* shows diminution of contractile power, in proportion to the amount of the degeneration of tissue. The A.C.C. is increased and may equal the C.C.C. I have never seen the former *exceed* the latter. The slow, tonic contraction, is only present in the very late stages when the peripheral nerves are implicated by secondary degeneration.

CASE XX.—*Pseudo-hypertrophic paralysis, of seven months duration. Electrical reactions indicating healthy nerve and partially diseased muscle.* E. A., æt. 7, male. The patient, for whose case I am indebted to my colleague Dr. Donkin, was stated to have been well till seven months ago. His mother then noticed for the first time that he dragged his left leg. He became very liable to fall down when walking or running. Five months ago slight flexion of the knees was noticed. Family history healthy.

At present the patient is healthy looking. All the muscles of the body except those of the legs and nates are spare, but otherwise not remarkable. The gluteal regions are distinctly enlarged and the calves of the legs very markedly so, each measuring nine inches in circumference at their widest part, while the thighs at the thickest portion are only nine and a quarter inches. They bulge outwards, are firm and hard, and the skin covering the muscles is tense and shining. In both feet there is marked talipes equinus, with a slight tendency inwards. The motions of the upper extremities are normal. Those of the trunk are evidently weak, as the patient has difficulty in sitting up any length of time, and in moving readily about, which he does imperfectly with the assistance of his hands. When sitting up he supports his body by using both arms as crutches. When lying on his back he moves the limbs fairly well, but sluggishly, and the actions of the feet, and especially its flexors, are very feeble. He walks with a feeble, unsteady, waddling gait, the legs widely apart, swaying the body from side to side, and bringing the feet down with a stamp. When lying on the floor and told to get up, he does so in a characteristic manner, by turning on his face, getting on his hands and knees, then on all fours, then drawing the feet to the hands, and finally climbing up his legs till he reaches the erect position with a sudden jerk at the end.

Electrical Reactions.—The nerve trunks throughout the body are followed by normal responses to both currents, with very slight comparative diminution in those of the legs. Electricity applied directly to the muscles, shows that all those but the enlarged ones are normal. These latter present the following peculiarities:—With faradism the reactions are markedly diminished, and with galvanism the contractions are vigorous, the A.C.C. = C.C.C.

CASE XXI.—*Pseudo-Hypertrophic Paralysis of seven years duration, nerves healthy, complete destruction of muscle.* W. H., æt. 9, male. The patient is said to have been healthy till two years of age, at which time he had a "fit." From this he recovered, but some weeks afterwards it was noticed that he walked lame with the right leg. This continued, and two years subsequently both legs appeared to be weak. This has gradually increased since; so that during the last year or so he has been unable to walk, or even stand.

At present the boy is in good general health. He cannot sit up in bed, and when made to do so falls back on the pillow, being unable to support himself. When lying on his back the movements of the head and neck appear normal. The arms and hands are very weak. There are no movements whatever of the shoulder-joints, the flexion of the arm, hand, and fingers, is very feeble, and the extension of the hands and fingers almost nil. The movements of the legs are very weak. He can draw them up in bed but very feebly, and only with irregular jerks. There are no movements of the feet or toes. Both sides of the body are nearly equal. The special senses, and general sensibility are normal. The skin has a mottled appearance and is cold and flabby. The muscles of the head and neck appear normal. The deltoids are much enlarged, and hard and brawny to the feel. The triceps are also much hypertrophied. The biceps are small, but are much indurated. The extensors of the forearm are not enlarged, but they feel dense and abnormally firm; the flexors appear normal. The muscles of the trunk are very thin but otherwise seem healthy. Those of the thighs are small but very hard. The calves of the legs are greatly enlarged, so as to be about double their normal circumference. The muscles of the extensors of the foot appear smaller than usual. Both sides are about equal. Tickling the soles of the feet produce no movements, and the patellar tendon reflexes are absent.

Electrical Reactions.—Faradism to the median and ulnar nerves causes normal contractions. To the musculo-spiral there is extension only of the fingers and thumb, and this is somewhat limited. To the flexors in front of the forearm normal contractions; to the extensors with the strongest current only very faint responses; much diminished reaction to both biceps and triceps, and none whatever to the deltoids, with the strongest currents. In the leg all the nerve trunks are normal. To all the affected muscles great diminution of response, especially in those of the thigh, and in the extensors of the foot and toes. *Galvanism.* To the nerve trunks throughout, normal. To the deltoids with the strongest currents, no response. To the triceps and the biceps, the action is much diminished, A.C.C. = C.C.C. Contractions rapid.

The same to the extensors of the hand and fingers. Here also it is noticed that when a strong current was used, the A.O.C. = A.C.C. The application to the flexors of the hand and fingers caused normal responses. To all the affected muscles of the lower extremities, the reactions are the same as those mentioned above, namely, quantitative diminution, A.C.C. = C.C.C., and with strong current, A.O.C. = A.C.C. Contractions rapid.

AMYOTROPHIC LATERAL SCLEROSIS.

The electrical reactions in this disease are the same as in Progressive Muscular Atrophy, and a study of the responses of this is equally applicable to Amyotrophic Lateral Sclerosis. It is scarcely necessary to say that the symptoms are very different, and upon them must depend the distinction between the two affections.

CASE XXII.—*Amyotrophic Lateral Sclerosis of three years duration. Electrical reactions indicating healthy nerves, and incipient disease of muscles.* C. O., æt. 30, male, shopkeeper, under the care of Dr. Buzzard, to whom I am indebted for an opportunity of observing the case. The patient states that he was quite well till three years ago, about which time, without obvious cause, he experienced weakness in the left leg, and a tendency to drag the toes along the ground. This began very insidiously, and increased very gradually, and was from the first accompanied with stiffness of the muscles. Some months afterwards, weakness of the left arm and hand was noticed. This also progressed very slowly during the next eighteen months, after which, the right leg gradually became affected in a similar manner, and this subsequently extended to the arm on the same side. The whole course of the affection has been very slow and gradual, there have been no pains, no bladder or rectal disturbances, and no alterations of sensibility. There have been occasional involuntary twitchings of the limbs, and recently they have been especially rigid. The general health throughout has been good.

The patient is a stout, robust looking man. All the functions and special senses are healthy. The face is normal. The muscles of the neck are slightly stiff and weak. The arms and hands of both sides are very feeble, especially the left. All the movements on the right side are performed naturally, but are slow and weak. The fifth finger cannot be adducted, but lies in a state of abduction. On the left side the patient cannot raise his arm above the head, he cannot fully extend the hand beyond on a level with the arm, the wrists have a tendency to drop, he cannot extend the fingers, and the grasp of the right hand is 60 lbs., the left 25 lbs. He cannot supinate the left forearm although he can pronate it. On the right side there is slight rigidity of all the muscles, but on the left this is well marked and requires considerable force to overcome their contraction. There is no apparent wasting of the arms. The legs are very weak. When in bed the patient can move the right one fairly well, but the left is almost immovable and can only be raised from the bed an inch. None of the joints on the left side can be moved at all. The movements of even the right foot and toes are very limited. The patient can stand and even shuffle along with assistance, the gait is stiff, and the feet are dragged along the ground. The left limb is so stiff and rigid that no ordinary force can bend any of the joints, and the limb lies extended in a straight line like a rigid rod. The right is stiff but not nearly to the same extent. All the reflexes are much exaggerated, and the knee jerk and ankle clonus are well marked in both legs. Sensibility is everywhere normal. The left lower extremity is markedly smaller than the right, the thigh measuring an inch less in circumference than the other, and the calf of the leg three quarters of an inch. There is no apparent atrophy of special muscles but the extensors of the foot and toes look unusually small. The patient complains of no pain anywhere either in the back or limbs, and his general health is good.

Electrical Reactions.—Faradism to the nerve trunks throughout the body cause normal reactions except slight diminution of the right median and slight comparative increase of the left popliteal. The muscles all contract normally except the triceps, and the extensors of the foot and toes, in which there is distinct diminution of response. This is most marked on the left side. *Galvanism* to all the nerve-trunks appears to be followed by normal reactions. To the biceps muscles normal. To the triceps slightly diminished response, with A.C.C. increased, but not equalling C.C.C. All the muscles of the forearms especially the extensors contract vigorously to a moderate current, on the right side A.C.C. = C.C.C., and on left A.C.C. > C.C.C. In the muscles of the legs and especially the extensors of the foot and toes the response to Galvanism seems diminished, the C.C.C. > A.C.C., but the latter is increased. The electrical abnormalities are uniformally most marked on the left side.

BULBAR PARALYSIS.

The Electrical Reactions in this disease are the same as in progressive muscular atrophy. The nerves are universally normal, and the muscles of the chin, lips, and tongue, show all the usual signs of degeneration in proportion to the stage of the disease. I have not had recently under observation a sufficient number of cases of this disease to be able to give a typical example of the different forms.

CASE XXIII.—*Glosso-Labio-Pharangeal paralysis supposed to be of three years duration. Elecrical Reactions indicating healthy nerve and degenerated muscle.* A. E. æt. 56, male, piano-forte maker, under the care of Dr. Garman of the Highgate Infirmary, to whom I am endebted for permission to make observations on the case. Owing to the speech being almost unintelligible, and to his having no friends it was impossible to obtain anything like a connected history. As far as could be made out his chief ailments began about three years ago, with difficulty of speech, paralysis of the face and slowness of swallowing, which symptoms have increased to the present time.

On examination the patient presents all the usual and characteristic appearances and symptoms of Progressive glosso-labio-pharyngeal paralysis. He appears fairly intelligent, but whether or not his mind is sound is doubtful. The sight and special senses are normal. Sensibility everywhere healthy. The movements of the entire face are impaired, especially the lower part. The mouth is closed very slowly and imperfectly, and the lower lip hangs permanently open. All the other voluntary actions of the face are very deficient and sluggish. He cannot protrude the tongue beyond the teeth, nor can he move that organ to any extent within the mouth. The saliva constantly dribbles out of the corners of the mouth. There is no apparent atrophy of the muscles of the face, although the lips and its lower parts are very thin. The tongue is distinctly smaller than normal and is deeply furrowed with sulci and ridges. The speech is almost unintelligible, on account of its mumbling and indistinct character. There is no true aphasia. The patient swallows with considerable difficulty, and has to take great care, especially with liquids. He cannot masticate solid food, which has to be broken down for him. In other respects the general health of the patient seems fairly good but his limbs and body generally are weak, and accompanied with a slight tremor.

Electrical Reactions.—With faradism, the nerve trunks and muscles, react normally, there being only slight comparative diminution of response on the left side. With galvanism, the nerve trunks are healthy. Direct to the muscles, those of the upper part of the face are normal. Those about the lips, cheeks, and chin also react vigorously, but with slight comparative diminution. Here also the A.C.C. is increased, as compared with the frontal and other superior muscles, but the C.C.C. > A.C.C. The tongue could not be reached in order to be tested.

E. Paralysis from Disease of the Spinal Cord. Electrical Reactions demonstrating Degeneration of both Nerve and Muscle.

Poliomyelitis Anterior.

This disease is most common in children, hence called Infantile Paralysis, but it is by no means rare in adults. It may be acute or chronic. *Faradism.* In an acute case the excitability of the *nerve* begins to diminish, to the induced stimulus, about the third day. This may sometimes be preceded by slight and temporary increase of action. The impaired response rapidly increases, so that in seven or eight days it may be completely abolished. This remains absent unless recovery takes place, in which case the irritability of the nerve to faradism slowly returns, and this only occurs after voluntary motion is restored, and it remains imperfect for a long time after function is apparently normal. The action of the induced current applied directly to the *muscle* is precisely the same as that to nerve, but somewhat later in appearing, and is owing to the implication of the intra-muscular branches of the nerves. If there is any contractility of muscle after the second week, the prognosis is favourable and indicates that the nervous fibres are not completely degenerated, and are capable of restoration. *Galvanism.* This applied to *nerve* is followed by the same reactions as faradism, namely rapid loss of response. To *muscle* direct the conditions are different. From the first few weeks to several months, there is increased irritability of muscle, so that a feebler current is necessary to cause muscular contractions than in health. These are slow, tonic, and prolonged, and are accompanied with qualitative changes, the A.C.C. = C.C.C. or A.C.C. > C.C.C. in short there is the typical "Reaction of Degeneration." In about three months, more or less, this excess of galvano-muscular contractility diminishes, and subsequently sinks below the normal standard, still retaining the qualitative alterations. The exaltation of reaction indicates disease of nerve, and commencing alteration in muscle, without actual degeneration in the latter. The succeeding decrease of response points to atrophy and destruction of fibre. If recovery take place the electrical reactions gradually resume their normal conditions, but for long remain quantitatively diminished, owing to the chronic cirrhosed state of the nerve and muscle. If regeneration is absent, the diminution may advance to complete abolition, in which case we infer total destruction of muscle.

In chronic poliomyelitis the reactions are similar, but slower in development, and the increase of galvano-muscular excitability is not so well marked. The reactions may be incomplete, in which case from their amount, we may judge the extent of the disease in the nerve and muscle.

Case XXIV.—*Poliomyelitis Anterior Acuta of seventeen days duration. Nerves completely degenerated. Commencing alteration in muscles.* W. H., æt. two, male. The patient is stated to have been perfectly well seventeen days ago. He went to bed one night in his usual health and next morning he was found in his present condition. He had no fever, or pain in the back, but for some time past had been irritable and slightly indisposed.

At present the patient is a perfectly healthy looking child, and all his organs and limbs are normal except the right leg. This is completely immovable, and hangs limp and useless The muscles are soft and flabby but there is no marked atrophy, and the skin is cold, mottled, and purple. The tendon patellar and other reflexes, which are normal in the other limb, are completely abolished in the right. Sensibility normal.

Electrical Reactions.—Strong currents from both batteries applied to the nerve trunks of the right leg, fail to produce any contractions, Faradism directly to the muscles is also followed by negative results. Galvanism applied to all the muscles of the affected lower extremity, is followed by good contractions to slow interruptions, and these are sluggish, prolonged, and tonic in character. The A.C.C. most distinctly causes more vigorous contractions than the C.C.C.

Case XXV.—*Poliomyelitis Anterior Acuta of eighteen days duration occuring in an adult. Complete degeneration of nerve. Commencing alteration in muscle.* M. A., æt. 31, female, artist. Eighteen days ago the patient was in the most robust health never having had a day's illness in her life. She is a lady of unusual accomplishments and superior mental attainments and never suffered from any nervous symptoms. She went to bed one night in her usual health, and awoke next morning feeling feverish and generally unwell, which sensations continued all day. During the ensuing night she was restless and feverish, and next morning had a severe pain in her back, and weakness of her legs. This continued, and on the following day she could not stand, and could hardly move her legs in bed. This paralysis has continued ever since. In a few days the constitutional symytoms passed away, and she has since regained her good general health. She can assign no cause whatever for her illness.

At present the patient is in perfect general health, and all her organs and functions are healthy. She has no appearance of being of an emotional or nervous temperament. The right leg is almost completely paralysed, its only voluntary movement being an almost imperceptable flexion of the toes, the muscles are soft and flabby but there is no appearance of definite wasting. The left leg is not quite so absolutely useless, as there are very slight movements in the ankle and knee joints, but of a very limited character. In the right lower extremity there are no traces of cutaneous reflex action, and on the left this is almost, but not completely abolished. There is no trace of tendon reflex on either side, and no marked vaso-motor changes except that the feet are very cold. Sensibility is everywhere normal. The upper part of the body is healthy.

Electrical Reactions.—Both currents, applied to the nerve trunks of the right lower extremity produce no response whatever, even those so powerful as can scarcely be tolerated. The same to the external popliteal, causes very faint extension of the toes. Faradism applied directly to the muscles of both legs induce no contractions in any of them, even with the strongest current. Galvanism produces vigorous contractions to all the muscles on both sides equally, but these are slow, and tonic in character. In those on the right side the A.C.C. > C.C.C., and on the left A.C.C. = C.C.C.

CASE XXVI.—*Poliomyelitis Anterior Chronica of one year's duration. Almost complete degeneration of nerve. Marked alteration in muscle.* A. K. æt. 29, female, housewife. The patient states that she has been in good health till about a year ago. About this time she felt generally unwell, lost her appetite, had malaise, and other indefinite symptoms. In a few weeks her legs became weak and this increased so rapidly that in about a month she could scarcely walk. She had no fever or pain in the back, or bladder, or rectal troubles. This condition, in which she could only walk with great difficulty, continued for about five months, when in some respects she improved, and for about two months her powers of locomotion were comparatively good. After this however, weakness again ensued, so that a month ago she became so paralysed as hardly to be able to stand. This has continued and she has suffered from occasional attacks of shooting pains in the legs, especially during the night. About three weeks ago she noticed for the first time that there was stiffness and weakness of the hands and arms.

At present the general health of the patient is good and all the organs are healthy. There are no cerebral symptoms and she is perfectly intelligent. There is some difficulty in moving about in bed. She complains of paroxysmal attacks of shooting pains flying about all over her body. Sensibility is everywhere normal. The movements of the upper arms can all be performed, but weakly and slowly and the grasp of both hands is very feeble. Flexion and extension of the fingers are weak and unsteady, especially of the middle finger in both hands. The movements of the legs are very feeble and imperfect, even when the patient lies on her back. She can draw up her thighs and legs but very slowly. The movements of the feet and toes are almost gone, more especially on the left side. There are no traces of patellar or other reflexes. The patient cannot stand without assistance. Both deltoid muscles are considerably atrophied. Those of the upper arms are fairly nourished. The forearms are spare and thin, and both flexors and extensors appear wasted. The muscles of the ball of the thumb are markedly atrophied, but the interrossei are not especially so. The muscles of the thighs are small and thin but not extensively wasted. The flexors of the legs are much atrophied, and what is left is very soft and flabby. There are no prominent vaso-motor changes, but the skin of the extremities is cold. The irritability of the muscles to a mechanical stimulus is very distinct.

Electrical Reactions.—A moderate *faradic* current applied to the trunk of the ulnar nerve produces vigorous and apparently normal contractions. The same to the median and musculo-spiral on both sides has no effort. A much stronger current to the median, causes very slight flexion of the thumb on the right side. As strong a current as can be borne to the median causes only slight flexion of the wrist and pronation of the forearm. The same has no effort on the musculo-spiral nerve in extending the hand or fingers, and there is only a trace of extension of the thumb. Faradism applied directly to the deltoids with a very strong current, causes slight contractions at the anterior and posterior parts of the muscles, but none whatever at their middle. To the biceps and triceps of the right side there are fair contractions but on the left they are greatly diminished, and to the triceps there is no response. A moderate current causes good contractions of the Flexor Carpi Ulnaris, and slight to the common flexor of the fingers on both sides, but has no effect on any of the other superficial muscles of the forearm. With a strong current the flexors of the wrist and Extensor Carpi Radialis respond very feebly, and the extensors of the fingers and Extensor Carpi Ulnaris do not act at all. The small muscles of the hand contract fairly well to a strong current. Both sides present much the same conditions, only somewhat more advanced on the left. *Galvanism* applied to the deltoids, causes somewhat sluggish contractions, the C.C.C. > A.C.C., but the latter increased. To the muscles of the upper arms the responses seem normal but to the triceps of the left side much diminished, C.C.C. > A.C.C. The responses to the Flexor Carpi Ulnaris appear normal, only the A.C.C. is somewhat increased. The same current applied to the other flexors of the forearm show diminution of response, A.C.C. = C.C.C., and the contractions are slow and tonic in character. The extensors of the fingers respond moderately, C.C.C. > A.C.C., but the latter is increased, and in those of the wrist the response is much diminished, A.C.C. > C.C.C. Both arms to galvanism are much the same in character, but more advanced in degree on the left side where there is a general comparative diminution of response.

To the lower extremities in general it may be said that there is almost total loss of reaction with faradism to both nerve and muscle. To galvanism there are fair contractions when applied directly to the muscles. To the flexors, C.C.C. > A.C.C., the latter increased. To the extensors, A.C.C. = C.C.C.

CASE XXVII.—*Poliomyelitis Anterior Chronica of six months duration. Total degeneration of both nerve and muscle.* C. S., æt. 2, male. The mother of the patient states, that the child was perfectly well till about six months ago, when it suffered from measles. On recovering from this it was noticed that his legs were weak. This has continued to increase till the present time. Nothing special was noticed concerning his arms.

At present the patient's general health is good. He cannot stand, and his legs sink under him. When lying on his back he can move the limbs fairly well. Owing to the youth and fretfulness of the child it is difficult to make out the exact conditions. The skin of the leg is cold and cyanotic, and there is no marked atrophy of the muscles. The patellar reflex is very slight but not absolutely abolished. The mother has not observed anything unusual about the arms, and it is difficult to ascertain anything for certain in this respect except that there is no very apparent paralysis.

Electrical Reactions.—Faradism to the median and ulnar nerves is followed by normal responses; to the musculo-spiral trunk by no action whatever even to the strongest currents. Applied to the flexor muscles of both arms, there are normal contractions. To the extensors of both fore-arms, no action, except slight extension on the ulnar side on the left, and slight extension of the fore-finger on the right side. Galvanism, as regards the nerve trunks, is the same as Faradism except that to the musculo-spiral there is slight action to a strong current. Applied directly to the flexors, the reactions are normal, except that A.C.C. is slightly increased. To the extensors generally, there are very feeble reactions to very strong currents, and to the extensors of the fingers in particular none at all.

F. PARALYSIS FROM DISEASES OF THE SPINAL CORD. ELECTRICAL REACTIONS VARIABLE ACCORDING TO THE SEAT OF LESION.

MYELITIS.

Under this head may be classed all those acute and chronic inflammatory diseases of the spinal cord which have not yet been described. In short those in which the lesion is not confined to any definite functional tract, but is more irregularly developed. In such cases the electrical reactions depend entirely upon the nervous structures involved by the disease, and they often form a means of assisting us to arrive at the seat and extent of the morbid condition. Here, as in other diseases, if acute, or in the early stages of chronic affections, the responses may at first be quantitatively increased from hyper-excitability of the nervous tissues. In very chronic cases from any source there may be quantitative diminution, as a result of functional inactivity and secondary degeneration in the motor tracts. If the white columns only are diseased there is paralysis, with no alteration of nutrition or in the electrical reactions. If the anterior cornua of the grey matter are degenerated there is structural change in nerve or in muscle, or in both, with corresponding electrical modifications.

The entire length and thickness of the cord may be destroyed, in which case the clinical symptoms would be apparent, in addition to the complete and general abolition of electrical phenomena. If a portion only of its whole thickness were degenerated there would be abnormal reactions to the parts derived from this segment, with healthy tissues above and below. Complications of various kinds, and in different localities may occur which may render a definite diagnosis extremely difficult, but a careful electrical research seldom fails to give some clue to the mystery. It would be impossible in the present treatise to give an example of all the varied modifications which may arise in myelitis. The following cases are illustrative of the chief phenomena to be met with.

CASE XXVIII.—*Myelitis of five years duration. Probable disease of the antero-lateral and posterior columns Electrical reactions, normal.* A. B. æt. 30, labourer, male. The patient states that he was in good health till five years ago, when without obvious cause he gradually experienced weakness and numbness in his legs with the feeling of a tight cord round his waist. This very slowly increased and gradually affected the arms. For the last year or two he has suffered from great constipation and difficulty in passing water.

At present the patient is in good general health, his organs, special senses, and intelligence are normal. The head and neck are healthy in every respect. The arms and legs are weak and feeble, and in all his limbs there is a tremor increased on exertion or excitement. The movements of the arms are very weak, and the grasp of the hands very feeble. He can walk, but with great difficulty, the gait is unsteady, he staggers, and has slight incoordination as well as weakness in his movements, which is much increased with closed eyes. There is no trace of cutaneous or tendon reflexes. Sensibility in the feet and legs is much diminished and in the hands and arms slightly so. There is no atrophy of muscles.

Electrical Reactions.—To the nerve trunks and muscles these are normal with both currents.

Case XXIX.—*Myelitis of thirty years standing. Probable disease of the white columns. Electrical reactions quantitatively diminished.* L. M., æt. 48, female. The patient states that she was healthy till eighteen years of age. About this time she first noticed a slight failure in the motion of one of her fingers. This very slowly increased, and involved the other fingers and hand. Subsequently the paresis attacked the other upper extremity, and was accompanied with loss of sensation. The legs also became attacked in a similar manner. This increased, but very insidiously, for the next ten years, at the end of which time she was almost completely paralysed in all four extremities. The muscles became very stiff, but at that time she could move about a little with assistance. Since that period, that is during the past twenty years, she has lived the life of a plant. She has been unable to move any part of her body except her head. Her general health and special senses have been good.

At present the general health is not impaired. The patient is perfectly intelligent. She sits on a chair unable to move anything but her head, which with all its organs is healthy. There is no trace of movement in either of the upper extremities. The legs can be moved a little but to a very limited extent. She can support the weight of her body but cannot walk. There is great rigidity of all the muscles and the flexors are all in a high state of contracture. There are frequent involuntary twitchings of the muscles and limbs. The reflexes of the lower limbs are much exaggerated, including those of the patellar tendons, and ankle clonus is present. The sensibility of the legs is much diminished, but that of the arms seems normal. There are no trophic or vaso-motor changes, indeed the patient is very stout and well developed. There is slight incontinance of urine and constipation of the bowels.

Electrical Reactions.—To all the muscles and nerves of the paralyzed parts the reactions of both currents are diminished, and require a much more powerful current than in health to produce contraction, otherwise they are normal, there being no qualitative changes.

CASE XXX.—*Myelitis of six months duration. Probable disease of the white columns and grey matter. Electrical reactions quantitatively and qualitatively changed.* A. R., æt. 34, female, housewife, has always been of nervous and somewhat delicate constitution, but otherwise well. About six months before admission, she became one day sick and feverish and experienced sharp pains in all her limbs, and weakness and numbness in her legs. Next morning she could not stand although she could move her legs when lying on her back. She lay in bed for three weeks and became worse, lost all power in her legs, and the arms became affected with weakness and soon afterwards almost completely paralyzed.

She suffered at first from general malaise but there was no pain in the back, nor any bladder, or rectal troubles. She was admitted into a hospital where she remained three months, during which time her general health was good and some improvement took place in the movement of her limbs.

At present the patient is a fairly healthy looking person, but pale and anæmic. She cannot stand or walk. When lying on her back in bed she can move her legs feebly. They cannot be fully extended owing to tonic contractions of the flexors of the thigh and leg. Attempts at passive extension cause great pain, and this can only be partially performed. There is no motion of the foot or toes, on either side. The muscles of the lower extremities generally are soft, flabby, and wasted. Bowels constipated, bladder not affected. The left arm which formerly was completely paralysed has recovered to a considerable extent. Its movements can be performed, but all of them are feeble. The fingers and hand are very awkward and clumsy, she cannot pick up small articles, &c. The grasp of the hand is very weak, the pressure exerted being only three pounds, as ascertained by the dynamometer. The right arm is still more paralysed, the wrist drops, and the patient cannot bring the hand level with the arm. The movements of the wrist and fingers are very feeble and limited. There is no pressure whatever with the grasp of the hand. The movements of the forearm and upper arm are also very imperfect. The muscles of both arms are much atrophied especially the right, and in both the extensors of the wrist and fingers are especially emaciated, and the flexors are slightly contracted. The head and neck are normal. There are no traces of reflex action or tendon reflexes in the legs. There is great loss of sensibility below the knees, but above them it appears normal. There is no pain or tenderness in the back, but there are occasional shooting pains in the limbs. There are no cerebral symptoms. The skin is covered with cold clammy perspiration.

Electrical Reactions.—Faradism. To the nerve trunks of the left arm, this causes very feeble contractions of the muscles, and in some of them there is no response whatever. A strong current applied directly to the flexors of the fingers causes moderate contractions. Neither the same, nor a much stronger stimulus, has any effect on the flexors of the wrist, or the extensors of the fingers and wrist, but there is a slight response to the radial extensor and that of the thumb. The small muscles of the thumb and little finger respond feebly to very strong currents. The right arm is much the same only more advanced, there being only slight response to the extensor digitorum to a very strong current, the other muscles failing to contract. The muscles of the upper arm are greatly diminished in irritability. To the nerves and muscles of the legs and thighs the strongest current fails to induce any contractions. The muscles of the trunk respond very feebly to strong currents. *Galvanism.* To the left forearm a moderate current produces fair contractions of the extensors of the hand and fingers, C.C.C. > A.C.C. The same occurs with the flexors but the contractions are not so well marked. To the right arm a strong current produces no effect on the Extensor Carpi Radialis, or on either flexor of the wrist, and very slight to the Extensor Carpi Ulnaris. The flexors and extensors of the fingers act moderately with a strong current C.C.C. > A.C.C. but the latter is increased. To the lower limbs there is no response whatever to a strong current applied to the nerve trunks. A powerful current to the muscles cause faint contractions C.C.C. > A.C.C. but the latter is increased.

The patient remained in the hospital, or under observation for thirteen months, at the end of which time her condition was as follows. The upper extremities were perfectly normal in every respect. There was no trace of atrophy, and the movements and power appeared normal. She could squeeze with the dynamometer 35 lbs. with the left and 25 lbs with the right hand. Her legs some months ago had been forcibly straightened. She can move her limbs freely in bed in every direction, but cannot stand. The reflexes were not tested owing to the patient having a large abscess on her back. Sensibility was normal. The patient left at her own desire. The electrical reactions on her leaving were. Faradism to all the nerves and muscles of the forearms and hands, as far as could be determined was normal, except that the extensors of both wrists showed considerable diminution. To Galvanism the actions appeared normal. The muscles and nerves of the legs were still considerably diminished in response to both currents although greatly improved.

Case XXXI.—*Myelitis of nine months duration. Probable disease of a limited segment of the cord. Electrical Reactions showing abnormal changes in a zone round the waist, with normal responses in the upper and lower extremities.* W. H., æt. 45, male, servant. The patient states that he has no history of syphilis and that he was in good health till about two years ago, when without any apparent cause he was seized with pain in the back. This pain lasted for some months. About nine months ago he began to experience weakness and numbness of the lower extremities. This continued gradually to increase, so that a month ago he was unable to walk, which condition has continued ever since. He has had good general health, only suffering from constipated bowels and slight difficulty in evacuating the bladder. During the last month his legs have become totally paralysed, the muscles have contracted, and he has felt a tight constriction round the waist.

At present the patient is a robust man. All his organs and functions are healthy. He has no pain in the back. About five inches above the umbillicus the patient complains of the feeling of a tight band round his body. Above this line all motion is normal, below it, totally abolished, and sensibility almost entirely lost. The muscles of the lower limbs are much contracted, and all the joints are so strongly flexed that even with force they cannot be extended. Although some of the muscles are somewhat soft and flabby there is no atrophy. Most of them are tense and rigid. There are frequent involuntary movements of the legs which cause considerable pain. Tickling or even touching the skin causes strong reflex movements. The tendon reflexes are greatly exaggerated, as are also the muscles to mechanical percussion. The bowels are constipated and there is incontinence of urine. The intellect and special senses are normal.

Electrical Reactions.—Over a zone about five inches in width round the body, the lower border of which is at about the level of umbillicus, Faradism and Galvanism applied to the muscles, even with very strong currents, fail to induce any contractions. Both above and below the band the electrical reactions are healthy.

III. PARALYSIS FROM DISEASE OF THE PERIPHERAL NERVES.

The Electrical reactions in diseases of the peripheral nerves vary according to the extent of the lesion, but on the whole are more complete and definite than those arising from degeneration of the centres. In Chapter VI has been described the anatomical changes which take place in a motor nerve which has been experimentally divided, with the Electrical reactions which as a consequence follow. Precisely the same conditions occur in disease when it seriously involves the structure of the nerve, and is termed "*the severe form*" of peripheral paralysis. Here there is total loss of response, with both currents when applied to the nerve trunk, total loss of farado-muscular excitability, and the Galvanic current direct to the muscular tissue gives the characteristic signs of the reaction of degeneration, the whole indicating more or less complete destruction of both nerve and muscle. "*The slight form*" of peripheral paralysis is present, when there is loss of voluntary motion with normal electrical reactions, showing, that although the lesion is sufficient to cause paralysis, it has not led to structural changes in either nerve or muscle. Between these two extremes there is every variety of intermediate condition, constituting, "*the middle form*" of peripheral paralysis, in which although not complete, there is evidence of more or less organic degeneration of either nerve or muscle or both these together. The prognosis of the mild form is favourable, recovery usually being complete in two or three weeks, with or without treatment. That of the severe form is unfavourable, and if a cure takes place at all, it is only after many months, and even then it is incomplete. In the middle forms, the prognosis varies according to the severity and extent of the disease.

These different degrees of nerve degeneration may all arise from the same or different affections of the nerve, causing a varying amount of destruction of its tissues. There may be simple quantitative *increase* of electrical response, as is seen in irritative lesions, and in the very early stages of severe diseases, but this is usually slight and temporary. Frequently there is quantitative *diminution*, and this in proportion to the histological alteration of the tissues. Finally in all serious affections of the nerve there are *qualitative* changes in the muscle. The explanation of these phenomena is precisely the same as that already given for similar results following diseases of the spinal cord, namely, the separation of the tissues from their nutritive elements in that centre. By the electrical conditions, we are enabled accurately to determine the exact pathological state of nerve and muscle, the stage of its progress, and in most cases to hazard with tolerable accuracy, its prognosis.

A. Slight form of Peripheral Paralysis.

Case XXXII.—*Paralysis of the musculo-spiral nerve of two days duration. Electrical reactions quantitatively increased.* A. W., æt. 37. male, potman. The patient states that he was perfectly well till about two days ago. He went to bed in his usual health and on waking found his left arm weak, which has continued so since.

At present the patient is a healthy man. There are no abnormal appearances of the limbs. The left wrist and fingers are very weak, and the former drops. He cannot extend the hand or fingers. The grasp of the hand is fair, but not nearly so strong as the other. The movements of the fore, and upper arm are normal.

Electrical Reactions.—All the nerves and muscles of the body are normal except the left musculo-spiral, and the muscles it supplies. Both currents applied to these, cause much more vigorous contractions than to the opposite and healthy side.

Case XXXIII.—*Facial paralysis of three weeks duration. Electrical reactions normal.* L. B. æt. 23, female, machinist. The patient states that she has suffered for many years from facial neuralgia on both sides, and pain in the right ear, otherwise with the exception of general nervousness, she has been in good health till three weeks ago. About this time it was first noticed that her face was drawn to the left side, which condition has continued ever since.

At present the patient although of a nervous temperament is in good general health. She complains of earache and neuralgia on the right side of the face, and frequent headaches. The sensibility is normal. The face when at rest is slightly drawn towards the left side, where the markings on the skin are most distinct, and this is still more apparent when movement is attempted. The motions of the right side are markedly deficient. Both eyes can be closed. There is slight indistinctness of speech. The movements of the tongue are normal.

Electrical Reactions.—These are normal to nerve and muscle, and equal on both sides.

Case XXXIV.—*Paralysis of the median nerve of three weeks duration. Electrical reactions normal.* F. S. æt. 53, male, mason. The patient states that he was quite well till three weeks ago, on waking one morning, and without apparent cause he experienced severe pain in the shoulder and along the inner side of the right arm. Next day this was much increased, and has continued ever since. A few days after the onset of the pain, the arm and hand became weak.

At present the patient is a healthy man. He has severe pain, limited to the shoulder and inner side of the right arm. The median nerve can be felt through the skin, hard swollen and very tender to the touch, from the axilla to the elbow. The movements of the entire limb are feeble and imperfect. Flexion of the hand and fingers is extremely feeble and the grasp of the hand is almost nil.

Electrical Reactions.—Both currents applied to the right median nerve, although they cause much pain, appear to produce the same muscular contractions as on the other side. Both currents applied to the motor points of the muscles themselves, caused contractions like those on the healthy side.

B. MIDDLE FORM OF PERIPHERAL PARALYSIS.

CASE XXXV.—*Facial Paralysis of three years standing. Partial loss of voluntary motion. Structure of nerve partially altered, that of muscle healthy.* M. G., æt. 41, female, machinist. The patient states she has always been delicate, but has had no definite complaint. Three years ago while in her ordinary health she observed her face drawn to one side, which greatly increased during the next few days. After a time this somewhat improved but the condition has remained ever since.

At present the woman is in ordinary health. There is severe but not absolute paralysis of the right side of the face, the features being all drawn to the left, both at rest and on motion. There are the usual symptoms, the incomplete closure of the right eyelid, the smoothness of that side of the face, etc., and there are involuntary muscular twitchings of the affected muscles. The right ear is a little deaf, and she has slight difficulty in articulation. The palate and uvula are normal. There are no other nervous symptoms.

Electrical Reactions.—A current with both Faradism and Galvanism to the trunk of the 7th nerve, sufficient to cause vigorous contractions on the left side, have no effect whatever on the right. A very powerful current produces slight muscular response. Faradism applied directly to the muscles causes the same results. Galvanism to the muscles produces slight quantitative diminution but no qualitative changes.

CASE XXXVI.—*Paralysis of the Ulnar Nerve of one month's duration. Partial loss of voluntary motion. Structure of nerve altered, that of muscle healthy.* W. C., æt. 41, male, brass-finisher. The patient was quite well till a month ago when he fell on his right shoulder. A few days afterwards he experienced pain in that joint shooting down the arm, and soon afterwards gradual weakness of the arm ensued, with numbness in the fingers, which symptoms have continued ever since.

At present the patient is a healthy man complaining of severe pain in the right shoulder, shooting down the inner aspect of the arm. On manipulating the ulnar nerve it is distinctly tender from the axilla down to the elbow. There is numbness of the two inner fingers. There is no apparent wasting. The movements of the right hand and fingers are very weak, as compared with those of the other side.

Electrical Reactions.—To the trunk of the right ulnar nerve there is marked diminution of response to both currents. Faradism directly to the Flexor Carpi Ulnaris, abductor, and flexor minimi digiti, show considerable diminution of response. All the other nerves and muscles are healthy to Faradism. To Galvanism these three muscles are normal, if anything with slightly increased reactions. This patient completely recovered in four weeks.

CASE XXXVII.—*Facial paralysis of one week's duration. Structure of trunk of nerve altered. Its peripheral branches, and muscles normal.* H. H., æt 33, male, brewer. The patient states that he was quite well a week ago. Then without apparent cause he noticed that the left side of his face became immoveable, and without apparant cause. This has continued since.

At present the patient is otherwise a healthy man. He presents all the symptoms of almost complete paralysis of the 7th, nerve on the left side. The face is drawn to the right, he cannot close the left eye, etc., There is no abnormality of the uvula or palate.

Electrical Reactions.—With a current of Faradism which produces very vigorous contractions when applied to the trunk of the right facial nerve, there are none on the left side, but with a very powerful current there is slight response. Faradism applied directly to the muscles, produces the same effects on both sides of the face. With Galvanism to the trunk of the nerve there is much diminished action on the left side. To the muscle, slightly increased quantitative change, but nothing qualitative.

CASE XXXVIII.—*Paralysis of the Median Nerve of two weeks standing. Great loss of voluntary Motion; Partial degeneration of nerve and muscle.* G.L., æt. 45, male, rope maker. The patient states that he was quite well till a fortnight ago. On waking one morning he felt his right arm numb and weak, which has continued since.

At present the patient is a healthy man. The right hand and fingers are very weak, especially the flexors. The grasp of the hand is almost nil. The movements of the fingers are very limited, and he cannot use them for dressing himself or for other purposes. There is no marked wasting.

Electrical Reactions.—The Faradic current to the right median is followed by distinct diminution, but not total loss of muscular contraction. The other nerve-trunks are normal. Direct to the radical flexors and the muscles supplied by the median nerve there is also marked diminution of response, while to the extensors the reactions are normal. Galvanism to the median trunk indicates slight comparative diminution of irritability. The same current applied to the paralysed muscles produces a more marked contraction than to the others, but it is slow and tonic and the A.C.C. = C.C.C.

C. SEVERE FORM OF PERIPHERAL PARALYSIS.

CASE. XXXIX.—*Facial Paralysis of two months duration. Almost total loss of voluntary motion. Complete degeneration of nerve, with alteration in muscle.* L. P., æt. 21, Female, servant.

The patient states that although in good general health, she is of nervous temperament. Two months ago she went to bed one night in her usual health. Next morning, without obvious cause, she found the right side of her face paralysed, and this has continued ever since.

At present the patient is an otherwise healthy-looking person. The right side of the face is almost entirely paralysed, but not absolutely so. She cannot close the right eye, but there are slight movements of the eye-brows when she attempts to do so. The other movements of the features are almost abolished. Fauces and palate normal.

Electrical Reactions.—A very strong application of either current fails to elicit any response whatever to the trunk of the right facial nerve. Faradism applied directly to the facial muscles produces no result. Galvanism directly to the muscles, causes contractions with a current so weak that it has no action whatever on the healthy muscles of the opposite side. The contractions are slow and prolonged, and the A.C.C. > C.C.C. A year afterwards this patient had improved but not entirely recovered.

Case XL.—*Paralysis of the Musculo Spiral Nerve of ten days standing. Complete degeneration of nerve, with partial degeneration of muscle.* J. S., æt. 37, male, cutler. The patient states that he was quite well ten days ago, and went to bed in his usual health, having been drinking heavily. Next morning he experienced numbness of the right thumb and fore-finger. This continued, and the next day the wrist and fingers of the right hand were weak. This increased during the next few days, and in addition a slight choreic movement appeared in the arm.

At present the patient is otherwise a healthy man. The choreic like movements in the arm have ceased. There is no evidence of lead poisoning. The parts are normal everywhere except the right forearm and hand. The movements of the right hand and fingers are very feeble, there is wrist drop, and the patient cannot extend the hand, which is kept greatly flexed. There is no trace of extension of the fingers. The grasp of the hand is feeble. Pronation and supination is normal. There is no marked wasting of the muscles. The sensibility is normal.

Electrical Reactions.—Both currents applied to the trunk of the musculo-spiral nerve, produce no effect whatever on the extensors of the wrist or fingers. Faradism directly to these muscles causes no contractions, even with strong currents. Galvanism direct to the affected muscles produces contractions about equal to those on the healthy side, but slower and more tonic in character, and the A.C.C. = C.C.C. The reactions to the flexors and other muscles are normal.

CASE XLI.—*Facial Paralysis of* 4½ *years standing. Almost complete loss of voluntary motion. Nerve completely degenerated. Muscle almost completely degenerated.* G. Y., æt. 6, male, schoolboy. The patient is stated to have been taken ill four and a half years ago, when his face became twisted, and this has continued ever since.

At present the patient is otherwise healthy. He suffers from all the usual symptoms of almost complete paralysis of the right facial nerve, difficulty of closing the eye, etc. He also suffers from headaches.

Electrical Reactions.—The strongest currents of both batteries fail to produce any effect when applied to the trunk of the right facial nerve. Faradism applied directly to the muscles is also followed by negative results. Galvanism with very strong currents, direct to the muscles, produces very feeble contractions, which are almost imperceptible, the A.C.C = C.C.C.

CASE XLII.—*Paralysis of the ulnar and musculo-spiral nerves,* *of eleven weeks duration, as a result of pressure. Great loss of voluntary motion. Advanced degeneration of nerves and muscles.* R. L., æt. 23, male, bricklayer, under the care of Dr. Sturges. The patient states that sixteen weeks ago being in perfect health, he broke his leg. At the end of a fortnight he began to go about on crutches. Three weeks after this he noticed that his left hand became weak, and this has continued ever since. He has not observed any affection of the other arm.

At present the patient is a perfectly healthy man with the exception of his upper extremities. He is a very heavy bulky subject. The trunk and shoulders are normal. The movements of the shoulder joints are healthy, as are apparently those of the entire right upper extremity. The actions of the left elbow joint are fair, but much feebler than on the opposite side. There is complete wrist drop and the extensors of the hand and fingers are absolutely paralysed, there being not the slightest trace of movement. The wrist and fingers can be flexed, but feebly, and the grasp of the hand is almost nil. The grasp of the right hand, appears weaker than normal. The size of the left arm below the shoulder is uniformly considerably smaller than the other, but no special muscles are atrophied. The muscles are flabby, and the limb is cold and purple. There is no rigidity, and the joints are quite flexible by passive motion. The wrist and fingers are kept in a state of flexion, which can be easily overcome. The sensibility of the skin is normal.

Electrical Reactions.—Faradism. On the right side the median and ulnar nerves are healthy, but the musculo-spiral is markedly diminished in reaction. In the left arm the median nerve is normal. The ulnar is greatly diminished in excitability, there being only slight flexion of the thumb when its trunk is irritated above the elbow. There is no response whatever when the musculo-spiral is stimulated with a moderate current but with the strongest there is very slight response. Faradism applied to the muscles on the right side causes apparently normal contractions, except to the extensors of the fingers and wrist, which are somewhat diminished in response. On the left side there is great diminution to all the extensors, as with a strong current there are very feeble contractions of those of the fingers, and none at all of those of the wrist. The flexors appear normal. *Galvanism.* To the nerve trunks much the same reactions as to faradism. The flexors of the right side are normal. The extensors give fair contractions, but the A.C.C. is increased. The same condition exists in the biceps and triceps muscles. On the left side the flexors are normal except that A.C.C. is increased. To the extensors of the fingers the response is considerably diminished, and the A.C.C. increased. To the extensors of the wrist this is so greatly diminished as to require a very powerful current to produce any action, and A.C.C. = C.C.C. In the biceps and triceps the reaction is diminished, and A.C.C. > C.C.C. With a powerful interrupted galvanic current to the extensors of the wrist, there is a contraction at making the current followed by immediate relaxation, although the current continues to pass, there being no tetanic spasm. This tetanus is seen in all the other muscles.

IV. PARALYSIS OF DOUBTFUL ORIGIN.

Under this head are included those forms of paralysis, the exact pathology of which, has not as yet been actually demonstrated.

HYSTERICAL PARALYSIS.

The electrical reactions in hysterical paralysis to both nerve and muscle are practically always normal. In some cases there may be quantitative changes, but these are of slight degree, and qualitative alterations are never present. Increased response indicates general nervous excitability, and diminution sometimes occurs in very chronic cases from functional disuse of the muscles. In certain cases, in addition to the ordinary reactions, the electrical stimulus produces irregular contractions of distant parts, and even of the opposite limbs. This indicates great excitability of the nervous system, and more especially of the cord.

Case XLIII.—*Hysterical Paraplegia. Second attack of two month's duration. Complete anæsthesia, and loss of voluntary motion. Electrical reactions normal.*—H. H., æt. 27, female, charwoman. The patient states that upon the whole her general health has been good. Some few years ago her husband died, and she was then compelled to earn her own living. A year ago she was seized with complete paralysis of the legs which continued eleven days, and from which she entirely recovered. About two months ago she gradually experienced a feeling of numbness in her feet accompanied with weakness. This has gradually increased so that now she has neither feeling nor motion in her limbs.

At present the patient's general health is excellent, and she is unusually robust-looking for a hospital patient. There is no trace of voluntary motion in any part of the lower extremities. The reflex actions and tendon reflexes are exaggerated. There are constant involuntary movements of the legs. There is complete anæsthesia and analgesia of the skin of the lower extremities. There is no pain anywhere. There is incontinence of the urine which constantly runs away without the knowledge of the patient. The other organs are healthy.

Electrical Reactions.—To both nerve-trunks and muscles these are normal. This patient subsequently recovered.

Case XLIV.—*Paralysis probably Hysterical. Second attack* *of three months duration. Widely diffused muscular contractions on electrical stimulus.*—A. B., æt. 21, female, sempstress. The patient states that she has never been a robust person, but has enjoyed fair general health till about a year ago. About this time without obvious cause she lost the power of her legs. For several weeks she was unable to move the limbs, after which she slowly recovered and continued in her usual health till about three months ago. Then, somewhat suddenly, in the course of two or three days, she again became paralysed in the lower limbs, for which she can assign no reason. Some few weeks afterwards, weakness was experienced in the arms, but the legs somewhat improved in power. These conditions have continued since.

At present the patient is an anæmic, delicate-looking girl, of highly nervous temperament. She is emotional and hysterical, but has never had severe attacks. She complains of pains in the head, back and limbs. The head and special senses are otherwise normal. Both arms are very weak, but nowhere specially so, and there are no trophic or vaso-motor abnormalities. Both arms are affected with a violent choreic-like tremor, which is greatly increased on attention being directed to it, or when attempts are made to do anything. This is sometimes so violent that the patient is unable to feed or dress herself. The lower extremities can be moved when the patient lies in bed, but in a jerky and irregular manner. She cannot stand or walk, and when she attempts to do so, even with assistance, her legs seem to sink from below her. There are no special muscles paralysed, or is there any wasting of their substance. The sensibility is considerably diminished everywhere, and especially in the lower part of the body. All the reflex actions are very vigorous, and the tendon reflexes greatly exaggerated. The mechanical irritability of the muscles is also much increased. There are no bladder or rectal troubles.

Electrical Reactions.—Both currents when applied to the affected nerves and muscles apparently produce normal reactions. When, however, the electrode irritated any nerve, it not only caused contractions of the muscles supplied by it, but also many of the others higher and lower down, and also some of those on the opposite side. These apparently reflex contractions were so strong, and so general, that it was extremely difficult to determine the local effect of the current.

LEAD PARALYSIS.

In this disease there may be abnormal electrical changes before the patient's attention has been directed to any loss of motion. In a case of lead poisoning observed by myself, in which the voluntary movements appeared unimpaired, electricity indicated normal reactions of the large nerve-trunks, but diminished response to their peripheral branches, also commencing qualitative alterations in the muscular fibre. The subject in this instance considered himself a perfectly healthy man. Paralysis, when it does appear may come very suddenly, and very rapidly develope abnormal electrical reactions. These consist of, speedy but seldom absolutely complete loss of response with both currents to certain nerve-trunks, and more especially to their peripheral terminations; there is increased irritability to galvanism of the affected muscles; the contractions are slow and tonic, with considerable increase of the anodal closure contraction. In short, there exist the typical reactions of serious neuro-muscular degeneration. In the further progress of the disease the electrical reactions may undergo all the phases already described as occurring in this condition, and may on the one hand end in recovery, or on the other, may proceed through all the stages to total abolition of response with faradism and galvanism to both nerve and muscle. As far as the actual character of the reactions themselves is concerned, their phenomena are much the same as are seen in poliomyelitis anterior; but their distribution, extent, and general progress are very different.

Case XLV—*Lead Poisoning. No paralysis. Electrical conditions indicating commencing alteration in the peripheral intramuscular nerves, and in the muscles.* A. B., æt. 40. male, house painter. The patient states that he has been a painter for twenty years, and has worked much with white lead. He has never been a robust man but has been in fair ordinary health till about a week ago. He was then attacked with pains in his bowels, and general weakness and indisposition, from which he has suffered since.

At present the patient is a pale sallow-complexioned man, but with the exception of his present complaint he is in his usual health. For the last week he has suffered from sharp attacks of colicy pains in his abdomen, coming on at intervals, but leaving in the interim an uneasy feeling. He has lost his appetite, and his bowels are greatly constipated, otherwise there are no abnormal symptoms. There is no weakness or wasting of the wrist or fingers, and the patient's attention has never been directed to any failing in these localities.

Electrical Reactions.—Both currents applied to the musculo-spiral, and other nerve trunks, an followed by normal responses. Faradism to the extensors of the wrist and fingers of both arms require a strong current to cause contractions, which are here much less vigorous than to the flexors or other muscles. Galvanism applied to these produces contraction apparently of normal force, but the A.C.C. is very markedly increased.

Case XLVI.—*Lead Paralysis of two weeks duration. Partial degeneration of nerve. Commencing alteration of muscle.* W. C., æt. 39, male, house painter. The patient says he has been a house painter for twenty five years. He has never had any actual illness, but for many years has not been a robust man. About a fortnight ago he felt unwell with indefinable symptoms, and pains and cramps in all his limbs. Having gone to bed in this condition one night, next morning he found his hands stiff and weak. This has gradually continued to increase ever since.

At present the patient is a slightly built, pale, and delicate looking man with a sallow complexion and marked blue line on his gums. His organs and special senses are healthy and he complains only of the weakness of his arms. Both Deltoid muscles are greatly atrophied. The muscles of both upper arms are thin, soft, and flabby. The forearms and hands are thin but cannot be said to be specially atrophied. The movements of both shoulder joints are extremely limited. He cannot abduct the elbows from the side more than a few inches, although all the other movements are performed, but very feebly. The movements of the elbow joints are weak, and the grasp of the hands is extremely feeble. There is no actual wrist drop, but there is marked difficulty in extending the hands and fingers. There is a well marked tremor of both arms and hands, and apparently confined to them, which is increased when attention is directed to it. Here and there in the affected muscles are fibrillary contractions of the fibres. The mechanical irritability of the diseased muscles is active and more so than in the healthy ones. Both sides are as nearly as possible the same.

Electrical Reactions.—Faradism applied to the ulnar and median nerves produces vigorous and healthy contractions. To the musculo-spiral trunk there is vigorous extension of the thumb, but all the other movements are much diminished. Applied directly to the flexor muscles there are good contractions. The same current to the extensors produces no effect except very slight extension of the ulnar side. The extensors of the thumb appear normal. With a stronger current there is no response whatever to the extensors of the fingers. The Biceps and Triceps muscles are normal. The anterior portions of the deltoids contract feebly to a strong current but the posterior portions do not do so. So far both sides of the body are equal. The left trapezius reacts somewhat less than the right, but contracts vigorously. The right rhomboid appears to contract freely, but slightly less than the left. The muscles of the hand appear to be normal. *Galvanism* is normal to the median and ulnar nerves, and somewhat diminished to the musculo-spiral. It is also normal to the flexor muscles of the forearm. To the extensors of the wrist and fingers, a current which produces no effect on the healthy muscles, causes in them marked contractions, slow and tonic in character, and the A.C.C. > C.C.C. To the Extensor Carpi Ulnaris the A.C.C. is not so well marked, and to the extensors of the thumb it does not appear to be augmented. To the Trapezius, Rhomboid, Triceps, and Biceps muscles the reactions are normal, except that in all the A.C.C. is slightly increased. To the Deltoids there is increased irritability, and a current which produces no effect on healthy muscle, with the C.C.C. causes a contraction in these with the A.C.C. Both sides of the body are equal.

CASE XLVII.—*Lead Paralysis of six months duration. Almost complete degeneration of nerve. Advanced alteration of muscle.* J. D. æt. 57, male, lead worker. The patient states that he has worked amongst lead for fifteen years, and has always enjoyed good health and never to his knowledge suffered from lead poisoning till six months ago. He then began to experience a pricking sensation in his fingers, and pains in his limbs, with weakness of the hands. These symptoms have gradually increased and continued up to the present time.

On examination the patient is a healthy looking man. The body generally is spare and thin. There is no marked special wasting of any of the muscles except those of the extensors of the hand; the thenar and hypothenar regions, and the interrossei are extensively atrophied. There are no movements of either upper extremities which are actually lost, but all from the shoulder downwards are feeble and imperfect. The extension of the hands and fingers more especially is weak, but can be performed slowly. Both sides are much the same, the right being somewhat more marked than the left. The sensibility of the skin is everywhere normal. There is a well marked blue line on the gums. The organs and other parts of the body are healthy.

Electrical Reactions.—The *Faradic* current to the median and ulnar nerves is followed by normal action. To the musculo-spiral there is only slight extension of the thumb. Applied directly to the muscles the biceps, and flexors of the hand and fingers, contract vigorously, the supinators and extensors of the thumb slightly, and the triceps and other extensors and small muscles of the hand not at all. The *Galvanic* current to the affected muscles causes contractions, but considerably diminished in degree, slow and tonic in character, and the A.C.C. in most of them equals the C.C.C.

CASE XLVIII.—*Lead paralysis of five months duration. Complete degeneration of nerve and muscle.* R. H., æt. 32, male house painter. The patient has been a painter for eighteen years. As far as he knows he has never had any symptoms of lead poisoning till eight months ago, when he was laid up for three weeks with an attack of colic. From this he recovered and remained well till five months ago, when he had another attack. While suffering from this he was seized with three "fits" of an epileptiform character, and soon after this he noticed that his hands were weak. This increased and has continued ever since.

At present the patient is a fairly healthy looking man, and he is well except his arms and hands. In the right side the disease is more advanced than in the left. The former arm he cannot raise to the level of the shoulder. The movements of the forearm are very feeble. There is distinct wrist drop and total incapacity to effect the slightest extension of the hand. The fingers are fixed and cannot be extended. The grasp of the hand is very feeble. The left upper extremity is the same but not quite so advanced. There is no marked atrophy of muscles except the extensors of the wrist, which on the right side seem to have disappeared.

Electrical Reactions.—*Faradism* to the Median and Ulnar nerves is normal; to the Musculo-spiral there is no response except slight action of the supinators and Ulnar extensor. Applied directly to the muscles on the front of the arm the reactions are apparently normal; to the extensors of the thumb fair contractions, but these are much diminished in the Ext. Carp. Ulnaris, and there are none to the extensors of the wrist and fingers even with a very strong current. The muscles of the hand act fairly well to a powerful current. This is the same on both sides, but less marked on the left. The *galvanic* current to the nerve-trunks is the same as the faradic. Direct to the extensors of the left hand and fingers, there are moderate contractions but considerably diminished as compared to the healthy muscles. These are slow and tonic in character and A.C.C.=C.C.C. The same to the Extensor Ulnaris of the right side, but to all the other extensors no response whatever to the strongest current of the battery.

CHOREIC PARALYSIS.

In some cases of chorea there is a considerable amount of paresis, which may sometimes even amount to paralysis. The electrical reactions in this condition are little known. In the cases which have come under my notice, however chronic, or however great the impairment of voluntary motion has been, I have never seen any diminution of response to the galvanic current, or any qualitative changes. In very chronic cases the reactions have been found normal, and in most of those more recent the responses were found exaggerated throughout the affected nerves and muscles. In a case of hemichorea cited below the electrical reactions were normal on the healthy, and comparatively much exaggerated on the choreic side, but unaccompanied by any trace of qualitative reactions. The number of cases at my disposal have not been sufficient to draw any conclusions as to the electrical conditions at the different stages of the disease. One singular fact has been noted that in a certain number of cases and more especially in adults, the reaction of faradism to the nerve-trunks is diminished, while that of galvanism is increased. In one case galvanism applied to the muscle showed the COC to equal the CCC. I can offer no explanation of these phenomena.

CASE XLIX.—*Acute Chorea of two months duration. Electrical reactions quantitatively increased.* H. M., æt. 6, male. The patient, although not robust, has been healthy till about two months ago, when restless movements were first observed. No cause can be assigned. They have continued to increase ever since.

At present the child is pale and thin but otherwise healthy. He presents all the characteristic signs of chorea affecting the head, body, and all the extremities. The movements are not violent but are well marked, especially in the face, hands, and feet. There is considerable muscular weakness, and he walks with a very unsteady gait.

Electrical Reactions.—Both currents, and especially the galvanic, when applied to all the nerve-trunks and muscles of the body show great readiness of response to very feeble powers of the battery. When these are so weak as to be scarcely felt by the operator they produce vigorous muscular contractions on the patient. No qualitative changes.

Case L.—*Hemichorea in an adult of one month's duration. Electrical Reactions normal on one side, and quantitatively increased on the other.* E. B., æt. 20, female. The patient was married eleven months ago and is now seven months pregnant of her first child. She has been well till a month ago, when without obvious cause, irregular movements appeared in the left arm and leg. These have continued since.

At present the patient is in good general health, and the intellect is normal. There are very well marked, but not actually violent choreic movements of the entire left side, including the face. The right side is quite unaffected. The reflexes are the same, and normal on both sides. The left limbs are distinctly weaker than those of the right.

Electrical Reactions.—Throughout the body the response to both faradism and galvanism is increased, so that very feeble currents cause vigorous contractions when applied to any of the nerve-trunks. This is, however, very much more marked on the left side, where the excitability as compared with the right is distinctly greater. No qualitative changes.

Case LI.—*Congenital Chorea in a patient ten years of age. Electrical reactions quantitatively increased.* J. W., æt. 10, male. Irregular movements of the limbs have been noticed in the patient from his earliest infancy, and they have continued ever since. He has an elder sister, who has been likewise affected from her birth. His intelligence has never been very good, and he cannot read or write. He is stupid and childish.

At present the general health is fairly good; the intellect, although not actually absent, is evidently blunted and altered. There are well-marked choreic movements all over the body, including the face and head. These are equally distributed. The patient walks in a shuffling, awkward manner, and is said to be easily fatigued. There is no special paresis, and the limbs, although thin, are nowhere actually wasted.

Electrical Reactions.—Feeble currents from both batteries, which the operator can scarcely feel, produce very vigorous contractions when applied to all the nerve trunks and muscles of the patient. There are no qualitative changes.

Case LII.—*Chronic Chorea, second attack, of ten months duration. Electrical reactions quantitatively diminished to faradism, and increased to galvanism.* S. M., æt. 15, female. The patient states that she has always been in good general health. Four years ago she suffered from an attack of chorea, which lasted a year, and which was the result of a fright. From this she completely recovered. Ten months ago restless movements appeared in all the limbs without apparent cause, and these have increased and continued ever since.

At present the patient is a robust, healthy-looking girl. She has choreic movements of all the limbs, trunk, head and face. These are very violent and constant, and the patient experiences much difficulty in sitting on a chair, lying in bed, and is incapable of doing anything for herself. She complains of weakness and languor.

Electrical Reactions.—A faradic current so strong as can scarcely be borne by the operator, causes only the very feeblest contractions when applied to the nerve trunks of the patient. When the current is further increased in strength they are very vigorous and otherwise normal, but the patient cries out with pain. A galvanic current—so weak that it cannot be appreciated by the operator—causes very vigorous contractions when applied to the nerve trunks of the patient. A current from 5 Leclanché cells causes marked contractions when the ulnar nerve is stimulated. The muscles themselves are also equally excitable. There are no qualitative changes except that the AOC = CCC.

PARALYSIS FROM SIMPLE ATROPHY.

It occasionally happens that after various exhausting diseases, or from other circumstances, the muscular system undergoes simple atrophy, and the body emaciates, and sometimes this may be more apparent in certain parts than in others. This is accompanied by corresponding weakness, and a condition may arise which has been mistaken for more serious organic disease of the nervous system. In such a case as this, the electrical reactions are perfectly normal in character, and their vigour depends on the actual bulk of the muscle which remains, thus distinguishing it from progressive muscular atrophy, and other more permanent affections.

CASE LIII.—*Paresis from Wasting of Muscles after prolonged rheumatism and inanition. Electrical reactions normal.* E. F., æt. 25, male: labourer. Under the care of Dr. Sturges. The patient states that four months ago he was perfectly well. He was then seized with a sub-acute attack of rheumatism of a severe character, which involved most of the joints of his body. With this he was laid up in bed for nine weeks: he suffered much pain, and did not have good nourishment or attention. On getting out of bed he noticed that he was very thin, especially his arms, which has continued since. Although latterly the pains in his limbs have improved, his general health has been very feeble: he has been depressed in mind and body, and his pecuniary circumstances have been very bad.

At present the patient is pale and weak, and he moves about with great difficulty. He has occasional pains in the joints and limbs, which are increased on movement; the left shoulder joint is stiff and grates when manipulated. There is no actual paralysis anywhere, but all the movements are feeble and imperfect, more especially those of extension of the arms, hands, and fingers. All the muscles of the body are small, soft, and flabby, those of the fore-arm and hands especially, the extensors of which on both sides are more particularly atrophied. The grasp of both hands is extremely feeble.

Electrical Reactions.—To the nerve-trunks with both currents there are perfectly normal reactions. The faradic current, applied directly to the muscles, showed that if their contractions were not so vigorous as in health, they were in proportion to their bulk. To galvanism also there was slight diminution, but no qualitative change.

PARALYSIS OF MALINGERERS.

In suspected cases of malingering, or in doubtful instances of paralysis, in which the patient is supposed to have some special interest in feigning disease, electricity may sometimes give most positive evidence. If any abnormal reactions exist, it is absolute proof of the presence of a morbid condition. On the other hand, absence of such does not of necessity demonstrate that the affection is fanciful, the diagnosis of which must then be ascertained by other means. If, therefore, a person claiming to be paralysed for pecuniary or other interests, exhibits abnormal electrical reactions, and if these coincide with the other facts of the case, we are in a position to state that anatomical changes in the nervous system certainly exist. The nature of these will be determined by our general knowledge of the circumstances before us. In the event of the responses being normal, in that respect the evidence is simply negative, and a decision must be arrived at from other data. In many of those difficult cases after railway and other accidents, when persons demand compensation from companies or individuals, the existence of the reaction of degeneration would be a fact of vital importance in favour of the applicant, as it would indicate that he was suffering from a serious nerve lesion. Such a demonstration is more conclusive in a Court of Justice than any amount of mere authoritative opinion.

Examples of these are detailed in Cases XXV. and LVII. In these it was suspected by both the relations and doctors of the patients, that the paralysis was not genuine. The electrical phenomena definitely proved the existence of real organic disease, which the subsequent progress of events fully demonstrated.

In the question of railway accidents, I myself have had no practical experience, but the following instance occurred in the practice of a professional friend, by whom I am permitted to give only a very superficial sketch of the circumstances.

Case LIV.—*Railway Accident. Alleged paralysis. Electrical reactions demonstrating degeneration of nerve and muscle.* Mr.——., æt. 50, having previously been in good health, was in a train which collided with another on a certain railway line. He was much shaken, and was taken home insensible. From this last symptom he recovered, but for some weeks afterwards was laid up in bed, suffering from the results of the shock. After a time gradual weakness was experienced in the lower extremities, which increased, till he could neither walk nor stand, and this lasted for many months. As the gentleman had been in receipt of a large income, of which his present condition deprived him, he brought an action for very heavy damages against the Railway Company who were responsible in the matter. There were a number of circumstances which raised the suspicion of the different parties, and grave doubts existed as to whether or not the paralysis was not greatly exaggerated, if not entirely feigned. Medical men were called to decide the question and as nothing positive in the case could be detected there was ample room for difference of opinion. An expert then electrically investigated the various tissues, and he found distinct evidences of both nerve and muscle degeneration. This with other circumstances enabled him with great certainty to establish the fact that organic disease of the spinal cord existed, and this of a tolerably advanced stage. This evidence was chiefly the means of procuring for the sufferer very heavy compensation, to which the progress of his disease in after years showed him to be fully entitled.

CHAPTER IX.

CONCLUSION.—THE PRACTICAL UTILITY OF ELECTRO-DIAGNOSIS.

IN the preceding pages an attempt has been made to give in detail, the electrical reactions of the different tissues in health and disease, and more especially in the different forms of paralysis. It is from a general knowledge of the facts thus displayed, and by their intelligent application in practice that useful deductions as to pathological conditions are to be drawn. As has already been insisted upon, like all other methods of physical diagnosis, electricity must not be depended on alone as the sole means by which we are to arrive at a just conclusion in investigating the nature of disease. It is only one of the aids we employ, but which in conjunction with other facts and observations is a most powerful auxiliary. A broad general view, and not a special one, should therefore be taken of the subject, and although this particular agent if scientifically employed will facilitate our methods of research, and the accuracy of our conclusions, we must not expect it by itself to act as a mysterious power which will give us every information without an enquiry into all the other circumstances of the case. While insisting upon this general principle, and disclaiming against the formation of too exalted notions as to the exclusive potency of the use of electricity in diagnosis, there are in this as in all modes of research certain instances in which it would appear that this agent actually gives us knowledge which cannot be arrived at from any other source. Of this many examples will be found amongst the cases already detailed in this book. In order more particularly to indicate the method of investigation employed, and the mode of drawing inference from the facts elicited, special attention is directed to the following selected cases.

1. *Electrical Reactions in a doubtful case of monoplegia, suggesting its cerebral origin.*—Case II. was that of a man who had suffered for four years from paresis of one arm, without any other definite symptoms. The fact of finding in so chronic an affection the electrical reactions normal, suggested a cerebral lesion; for peripheral paralysis and disease of the grey matter of the cord being thus disproved, it was very unlikely that any morbid condition of the lateral columns would have remained limited for so long a period. The diagnosis arrived at was subsequently proved to be correct by post-mortem examination.

2. *Electrical Reactions in a doubtful case of monoplegia, indicating it to be of spinal origin.*—Case XV. was that of a man who had suffered for five weeks from pain and weakness of his right arm, with slight atrophy of the limb. The question arose—was this due to a cerebral, spinal, or a peripheral lesion? The fact of the nerves being healthy to electrical tests proved that it was not the last, the muscular degeneration indicated that it was not the first, but this occurring in both limbs, demonstrated the spinal origin of the disease.

3. *Electrical Reactions in a doubtful case of monoplegia indicating it to be of peripheral origin.*—Case XXXVI. was that of a man who, after a fall, suffered from weakness of one of his arms. The fact of finding distinct abnormal electrical reactions in one ulnar nerve, with the muscles it supplied, and the remainder of the body being intact, proved the lesion to be a local one, and confined to the nerve in question.

4. *Electrical Reactions in a doubtful case of monoplegia supposed to be due to injury, but proved to be the result of progressive muscular atrophy.*—Case LV.—A. B., æt. 60, male, farm

labourer. The patient states that two months ago he was in good health, when he accidentally fell on a pitch-fork, a prong of which passed through the fleshy part of his upper arm near the axilla. He remained under the care of a local surgeon for some weeks, during which time he kept his arm in a sling, and after which the wound gradually healed. After this had taken place, the arm and hand remained weak, and got thinner, so that he came to London for advice.

On examination the general health was good. There was considerable paresis of the left upper extremity, from the shoulder downwards. The muscles were somewhat thin and flabby, and those of the hand were distinctly atrophied. There was no loss of sensibility. The right arm and remainder of the body appeared normal.

Electrical Reactions.—With both currents the nerve-trunks of the left upper extremity were normal, and the same as on the other side. Galvanism applied direct to the muscles of the left shoulder and arm caused vigorous contractions, if anything, slightly more marked on the paralysed side, and A.C.C. = C.C.C. The same reactions were discovered in the muscles of the apparently healthy right hand, and here also the A.C.C. was found considerably increased.

Several physicians and surgeons whom this man consulted came somewhat naturally to the conclusion, that the accident had, in some way, injured the nerves of the brachial plexus, and had, in consequence, induced the paresis and wasting of the left limb. In short, they considered the case one of traumatic peripheral paralysis. Electrical investigation, however, demonstrated that the nerve trunks were perfectly healthy; it showed marked alteration of the muscular structure of the affected extremity, and finally it indicated, in what was apparently a healthy limb, that this was undergoing incipient disease, as yet too slight to interfere with function. The result arrived at from the investigation was, that the patient was suffering from chronic progressive muscular atrophy in both upper extremities: that the accident had directed attention to his left arm in which the disease was furthest advanced, and that he attributed the loss of function to what was, in reality, an accidental complication of an already existing degeneration. This diagnosis was subsequently proved to be correct by the after progress of the case.

5. *Electrical Reactions in a case of double facial paralysis of cerebral origin on one side, and peripheral on the other, occurring in the same individual, and showing the distinctive differences of response.*—Case V. was that of a man who, among other disorders suffered from almost complete paralysis of both sides of the face. The electrical reactions on one side were healthy, while those on the other presented all the typical signs of nerve and muscle degeneration. This indicated that the former was probably of cerebral, and the latter of peripheral origin. The diagnosis made was, that there was a growth on one side of the brain, causing, by direct pressure, paralysis of the facial nerve on the same side, and by interference of voluntary transmission, inducing immobility of the face on the other side.

6. *Electrical Reactions in a case of supposed bulbar paralysis, proving it to be one of peripheral paralysis.*—Case LVI.—A. S., æt. 54, female, housewife. The patient states that she was quite well till six months ago. Then she began to suffer from general malaise and muscular weakness. This was accompanied with hesitation in her speech and dribbling of saliva from her mouth. These symptoms have continued very gradually to increase, till the present time.

On examination, the patient is a delicate, nervous woman. She complains of great general debility, so much so that she is unable to perform her ordinary household duties. There is, however, no actual paralysis, of the limbs. The special senses are normal and the intelligence appears intact. At rest, the face is not observedly altered, except that it is expressionless, and the lower lip hangs downward leaving the mouth open. On movement the under parts, especially those about the lips and chin, are distinctly defective in action, and are drawn slightly to the right side. Food collects in the cheeks, and the saliva frequently dribbles from the corners of the mouth. There is also some difficulty of mastication. The speech is slightly thick and mumbling. The movements of the tongue are deficient, and it is pushed over to the left side. There is no difficulty in swallowing. There is no apparent wasting of the face. The left side of the tongue is distinctly atrophied, it is twisted, puckered, and covered with deep furrows. The right side looks normal.

Electrical Reactions.—Faradism to the nerve trunks of the face indicates diminution, but not total loss, of response, especially on the right side. Applied directly to the facial muscles a very strong current is required to cause contractions. The right side of the tongue is also very sluggish in reacting, and on the left there is no response whatever to the induced current. Galvanism to the Facial nerve trunks also indicates deficient reaction, but when applied to the muscles themselves the responses are vigorous, somewhat prolonged, and A.C.C. = C.C.C. The continuous current to the right side of the tongue causes apparently normal reactions. On the left side they are comparatively increased, prolonged, and A.C.C. = C.C.C.

This case had visited many hospitals and seen many physicians, and the general opinion expressed was that the patient suffered from bulbar paralysis. This view I shared before applying electrical tests. Then, however, it was found that these exhibited the reactions usually associated with Peripheral nerve paralysis, instead of the muscular degeneration alone, ordinarily met with in bulbar paralysis. But the question arose, how could disease primarily attack the facial and hypoglossal trunks on both sides, and apparently these nerves only? A post-mortem examination, however, solved the problem. It was then found that the pons and medulla were healthy, the facial and hypoglossal nerves were atrophied, the former chiefly on the right, and the latter most on the left side. These conditions were the result of pressure from extensive disease of the bones at the base of the skull, involving the foramina through which these nervous trunks passed. It is not asserted that in this case the exact diagnosis was determined or expressed before death. In spite of the similitude of the symptoms to a central lesion, the peripheral nature of the electrical reactions were recognised, but the symmetrical character of the affection did not seem to be explained. In the face of this doubtful problem an opinion was postponed, as it was not thought advisable to place these electrical phenomena alone, against all the other probabilities of the case. As the facts, however, turned out, if a verdict of peripheral paralysis on both sides had been pronounced, in accordance with the reactions obtained, in spite of its apparent impossibility, it would have been correct.

7. *Electrical Reactions in a case of extreme irritability of the spinal cord, showing abnormal reflex responses.*—CASE XLIV. was that of a young woman almost totally paralysed in her lower extremities. When the electric current was applied to any of the affected nerves, not only were there violent general movements of the various muscles of the same leg, but marked contractions ensued in those of the opposite limb. This indicated great general hyper-excitability, and more especially of the grey matter of the spinal cord.

8. *Electrical Reactions in a case of supposed progressive muscular atrophy proved to be simple emaciation.* Case LIII. was a man sent into the hospital as an instance of progressive muscular atrophy, and his condition at first sight might easily have been mistaken for that disease. On electrical examination of the muscles they were all found healthy, and this with the general circumstances of the case, suggested the diagnosis of simple atrophy from emaciation as a result of inanition. This was subsequently found to be correct, as after a residence of a few weeks in the hospital, the patient completely recovered.

9. *Electrical Reactions in a case of supposed simple emaciation, the wasting proved to be due to progressive muscular atrophy.* Case XVI. strongly contrasts with the last one cited. It is that of a man who was admitted into the hospital suffering from general debility. He was perfectly healthy till six months before, when he was seized with violent vomiting. This continued for some months, so that, being unable to retain the larger part of his food, he became very weak, and lost two or three stones in weight. He was sent into the hospital as a case of dyspepsia and inanition. On examination, the patient was found generally much emaciated, there was no apparent special wasting of any individual muscle, and although all his limbs were extremely feeble, no special paralysis could be demonstrated. On electrical investigation the nerve trunks throughout the body was found normal, so also was the action of the faradic current when applied directly to the muscles. The galvanic current, however, indicated marked reaction of degeneration in several of the muscles of both arms, especially those on the left side, some of them being increased quantitatively, with the anodal exceeding the cathodal closure contraction. This led to the diagnosis of incipient progressive muscular atrophy, which was so far justified by the result, that although the patient

remained a considerable time in the hospital under the best circumstances, his malady continued to progress. In this case the electrical reactions discovered and established a diagnosis which, without their aid, could scarcely have been even surmised.

10. *Electrical Reactions found abnormal in the muscles of a house painter, before there were any other objective symptoms of disease.*—Case XLV. was that of a house painter who appeared at the hospital, as an out-door patient, suffering from trifling and indefinite dyspeptic symptoms, but without a suspicion or trace of paralysis. The nature of his occupation suggested lead poisoning of which, however, there were no typical symptoms. Electrical tests applied to the extensors of the hands and fingers, demonstrated a commencing degeneration of the muscles, although there was no loss of function, thus establishing the otherwise doubtful diagnosis of saturnine poisoning. The subsequent progress of the case further demonstrated this fact.

11. *Electrical Reactions in a case of supposed hysterical paralysis, proving to be chronic poliomyelitis anterior.*—Case LVII.—M. S., æt. 21, female. The patient states that she has always been in good general health. She has been occasionally nervous and hysterical, but has had no definite complaints. Seven months ago she suddenly became blind of the left eye, but from this, in a few weeks, she completely recovered. Shortly after this she noticed, for the first time, weakness in the left leg, and this has remained and increased up to the present time. For some weeks past, in addition, she has experienced a sensation of numbness in the left hand, but without apparent paresis.

At present the patient is a perfectly healthy-looking person. All the functions and organs are healthy. She can walk, but is very lame with the left leg. The foot is turned inwards, and the toes drag along the ground. When the limb is raised, the extension of the foot and toes is very weak and imperfect. The movements of the knee, and other joints, appear normal. There is no marked atrophy, and the remainder of the body is healthy.

Electrical Reactions.—Faradism applied to the left external popliteal nerve shows very great diminution of response, as compared to the other side, and requires a much stronger current to produce muscular contractions. The other nerve trunks are normal. Direct to the muscles of the left leg there is slight comparative diminution to all, but to the extensors of the foot and toes the contractibility is almost entirely abolished, with the strongest current. Galvanism to the external popliteal nerve, shows great diminution of response, and to the extensor muscles of the foot and toes there is also considerable diminution of reaction, the A.C.C. = C.C.C. and the contractions are slow and tonic. The other muscles of the leg, as well as all those of the other limb, are normal. On testing the arms, all the nerves and muscles are found healthy except the extensor carpi ulnaris, in which the excitability to faradism is almost abolished, and that to galvanism is increased, the A.C.C. = C.C.C.

This young lady had been under the care of several medical men, who unanimously pronounced her disease to be 'Hysterical,' and she was treated accordingly. The above investigations seem to have established the fact, that whatever the word hysterical may mean, this was a case of chronic organic disease, and probably of the anterior cornua of the cord, as we find degeneration of both nerve and muscle. A year afterwards the disease had considerably advanced.

12. *Electrical Reactions in a case of supposed feigned paralysis, proving to be Poliomyelitis anterior acuta.*—CASE XXV., was that of a young lady who was supposed by all her friends and

relations to be wilfully shamming, and was treated by them with great harshness, and by several of the leading physicians in London was said to be suffering from hysteria. The fact of finding extensive and severe degeneration of both nerve and muscle, demonstrated the existence of organic disease. The diagnosis made was acute poliomyelitis anterior, and the prognosis advanced was unfavourable. This has been so far established, that two years afterwards the patient could not stand, and the atrophy of both lower extremities has so increased as now to leave no doubt as to the serious and organic nature of the lesion.

13. *Electrical Reactions in the case of a patient demanding damages after a railway accident, proving under suspicious circumstances the claims to have been a genuine one.*—CASE LIV., was that of a gentleman, who, under peculiar and suspicious circumstances, claimed heavy damages after a railway accident. There were absolutely no objective symptoms in the case, except the electrical reactions, by which degeneration of certain nerves and muscles was established. This proof of organic disease was the chief means of convincing a jury to award, as the plaintiff deserved, substantial damages.

The above cases have been cited as illustrations of how electric tests alone have practically established the diagnosis with a certainty and accuracy which could scarcely have been determined by any other method. Such instances, although of the highest importance, are comparatively rare; but in the large majority of cases of paralysis, electricity, if not absolutely essential to the forming of a diagnosis, is the means of giving it a facility and precision which has become indispensable to the neurologist.

It was originally my intention to have formulated a table in which the electrical reactions were to be drawn up in order, with their equivalents in the different forms of paralysis. Such, however, would I believe be unscientific if not impossible, for as it has been already stated we cannot depend upon physical phenomena alone, but must rely on our general information. As a crepitation heard over the chest by a stethoscope does not by itself diagnose any particular disease, but only demonstrates a physical condition, which, in conjunction with other symptoms and signs enables us to arrive at the anatomical state of the lung; so electrical tests do not specify any form of paralysis, but only indicate certain conditions from which we may infer the morbid lesion. At the same time while submitting that the real value of the enquiry is only to be gained from a complete knowledge of the subject, certain generalizations can be drawn which may prove useful for the guidance of the student.

General Principles in the Electro-Diagnosis of Paralysis.

In a given paralysis, if the electrical reactions are perfectly normal, we may conclude, subject to the limitations already detailed, that it originates in an affection either of the brain or of the white columns of the cord. This distinguishes it from paralysis due to degeneration of the grey matter, or of the peripheral nerves. Paralysis from cerebral disease is usually hemiplegic, and from a spinal lesion, paraplegic in character, which constitutes a general distinction between the two. In irregular forms of loss of voluntary motion, such as in cross paralysis, or in paresis of one limb, in either case dependant on disease of the brain, or of the white columns of the cord; the difference is not to be made out by electric tests, as in both cases these would be normal. Hence such would have to be determined by the general symptoms, a matter often of great difficulty. Fortunately paralysis of a single limb from affection of the columns of the cord is extremely rare.

When the responses to electricity are greatly increased it indicates hyper-excitability of the nervous system, and when, in addition, reflex muscular contractions are produced in various parts of the body by stimulation of a nerve in the paralysed parts, it is further evidence of great irritability of the spinal cord, almost, if not quite, amounting to organic disease.

Abnormal electrical reactions, especially if combined with qualitative changes, are evidence of disease, either of the grey matter of the cord, or of the peripheral nerves. If these occur in the form of complete paraplegia, the certainty is that the cord is at fault; but if confined to the branches and muscles of a single nerve-trunk, the probability is that the lesion is one of peripheral origin. If one extremity or portion of an extremity is affected, the diagnosis is more difficult. In such a case the distribution of the paralysis is of great importance. When a limb has lost its power of motion as a result of disease of the *cord*, the abnormal electrical reponses may exist in one of three ways. (*a*). They may be uniformly distributed throughout the entire paralysed member, all the muscles being equally affected. This takes place in gross lesions involving a mass of the structure of the cord. (*b*). They may be distributed only to certain muscles forming *physiological* groups, irrespective of their nervous supply. For example, all the flexors of a limb, or its extensors, may present abnormal reactions, although they receive their nutritive influences from different sources. This occurs in chronic affections of the multipolar cells of the anterior cornua; and (*c*). Their distribution may be perfectly irregular, affecting the muscles neither in anatomical nor physiological groups. This often follows acute inflammation of the grey matter.

On the other hand, in *peripheral* paralysis, we never find either the entire limb, or physiological or irregular groups of muscles, presenting signs of degeneration; but these are distributed according to *anatomical* relations—in other words, to those structures only, which receive their nervous supply from a special nerve trunk, totally irrespective of their function.

Hence, in limited paralysis, the great distinction between those originating in the cord, or in a peripheral nerve lesion, is that in the former the limb is uniformly affected, or its muscles are attacked in physiological or in irregular groups, while in the latter they are affected according to their anatomical distribution.

Electrical phenomena also enable us to distinguish between the different varieties of paralysis arising from disease of the grey matter of the cord. If these, when abnormal, are uniform, and extend over an entire limb, we may conclude that the lesion is gross, *i.e.*, occupying a mass of its substance, as in myelitis. If they are confined to certain physiological groups of muscles, the disease has generally been chronic, and implicates the multipolar cells of the anterior cornua, as in progressive muscular atrophy. And finally, if the degenated muscles are attacked in an irregular manner, neither according to distribution or function, the disease has usually been the result of an acute inflammation of the anterior cornua, which has destroyed some of the nutritive centres, and left others intact, as in poliomyelitis anterior acuta.

Again, the electrical reactions may demonstrate degeneration of both nerve and muscle, which, if acute, is evidence of infantile paralysis, and if chronic, of disease of the grey matter *en masse* as in myelitis. They may also indicate disease of muscle with healthy nerve, which occurs in chronic lesions attacking the nutritive centres of the muscle only, as in bulbar paralysis. If nerve is found deficient in response, and muscle normal, it shows alteration in the former, the latter remaining intact, as is sometimes seen in the early stage of infantile paralysis.

In cases of limited disease of the grey matter, where the lesion is confined to one or more foci, as in the so-called mixed, or indiscriminate forms of paralysis, the distribution of the abnormal electrical reactions gives an index to the amount, extent, and position of the cord degeneration. For example, in Case XXXI., a zone of reaction of degeneration existed round the waist of the patient, with normal phenomena above and below. This, accompanied as it was with complete paraplegia and anæsthesia, indicated that a limited segment in the upper dorsal region was seriously diseased, and that the structure of the cord was elsewhere normal. If irregular patches of grey matter are similarly affected, sufficient to interfere with the nutrition of one or more of the anterior roots, the electrical reactions will indicate a corresponding change at the peripheral parts.

Such general considerations concerning limited electrical abnormalities as a result of disease of the grey matter of the cord, will usually enable us to distinguish them from one another, or from lesions of the peripheral nerves.

In peripheral paralysis, the electrical conditions indicate with exactitude, the extent and distribution of the disease. Paralysis with normal reactions is evidence of a slight and temporary form, the prognosis of which is favourable, sufficient changes having occurred to modify the transmission of voluntary impulses, but not to affect the nutrition of either nerve or muscle. Loss of response to the nerve trunks, with either current, points to nerve alteration, and this in proportion to its diminution of action. Loss of response with faradism to the muscle, indicates changes in the intra-muscular nerves, without necessary alteration of the fibres themselves.

Loss of response with galvanism to the muscle, shows modification or destruction of the muscular tissue, and this in proportion to the physical changes induced. The various shades and differences observed in cases of peripheral paralysis have already been described.

Cases occasionally come under notice in which there is little or no paralysis, and where there are no objective symptoms whatever. In these, early degenerations may sometimes be detected by electrical tests, before there are any definite symptoms, as was seen in Cases XV., XVI., XLV. and LV. Even when there is suspicion of disease, it may not be readily detected, and the existence of electrical change is a physical fact which, if demonstrated, establishes an otherwise doubtful diagnosis. Before sufficiently marked alterations have ensued to enable us accurately to measure and compute their locality or distribution, this may frequently be done with considerable accuracy by the same method.

Thus far, we may generalise with safety on the subject of electricity in diagnosis: to lay down more strict definitions would be too arbitrary. Doubtless, instances will occasionally arise, when all our means of investigation combined, fail to determine the true nature of the lesion. We can only hope that as our means of research improve, these mysteries will, in the future, be solved, and that the art of electro-diagnosis, although as yet in its infancy, may, by further development, constitute one of the means to this end.

GENERAL SUMMARY OF THE ELECTRICAL REACTIONS IN PARALYSIS.

1. In paralysis, when the affected nerves and muscles display normal electrical reactions, it indicates that their structure is anatomically healthy.

2. Quantitative increase of response with either current

to *nerve*, indicates augmented excitability of its substance. This may be due—*a.* to an irritative lesion—*b.* to absence of the inhibitory action of the brain.

3. This increased excitability is usually slight in degree and temporary in duration, except in certain chronic irritative lesions of the white columns of the cord, when it may be more permanent.

4. Quantitative increase of response with the *faradic* current to *muscle*, indicates increased excitability of the intra-muscular nerves, due to the same causes as in No. 2.

5. Increase of response with the *galvanic* current to *muscle* may occur under two circumstances—*a.* when the nerve trunk is not diseased, in which case it indicates hyper-excitability of its intra-muscular branches—*b.* when the nerve is degenerated, which is evidence of commencing alteration in the nutrition of the muscle, as a result of the removal of nervous influence.

6. Reflex contractions of muscles in different parts of the same limb, or in other parts of the body, following the electric stimulus of any special nerve, without any necessary qualitative change, indicates extreme hyper-excitability of the grey matter of the spinal cord.

7. Quantitative diminution of response with either current to *nerve*, indicates alteration in its anatomical structure. The amount of decrease is in proportion to the degeneration of tissue, and when electrical action is abolished, the nerve may be considered as totally destroyed.

8. Quantitative diminution with *faradism* to *muscle* indicates changes in the anatomical structure of the intra-muscular nerves, and the decrease is in proportion to the amount of tissue alteration.

9. Diminution with *galvanism* to *muscle* always indicates degeneration of its substance, and bears a relation to the

amount of the change, and this may occur with or without disease of the nerve.

10. Qualitative changes in muscle always indicate histological alterations in its fibres. There is no apparent proportion between the relation of one pole of the battery to the other, and the amount of anatomical change. The anodal contraction being increased, points to degenerative modifications.

11. Qualitative alterations in *muscle* may occur independently of disease of *nerve*, which may or may not be destroyed.

12. In paralysis from cerebral disease, it is the rule for the affected nerves and muscles to present normal electrical reactions, thus distinguishing it from paralysis due to disease of the grey matter of the cord, and of the peripheral nerves.

13. In cerebral paralysis there may be slight quantitative, but there are never qualitative changes. Slight increase of response being due either to an irritating lesion, or to a severance of the inhibitory influence; and slight diminution being caused by disuse of the muscles, or secondary degeneration of the nerves.

14. In paralysis from disease of the white columns of the cord, the electrical reactions are also normal, and present the same phenomena as in nos. 12 and 13. This distinguishes a lesion of the anterior, lateral, or posterior columns, from disease of the grey matter of the cord, or from peripheral paralysis.

15. The distinction between paralysis from brain lesion, and paralysis from disease of the white columns of the cord, cannot be detected electrically, as both are normal, but the distribution of the symptoms leaves little difficulty in diagnosis.

16. Abnormal quantitative and qualitative reactions al-

ways accompany diseases of the anterior cornua of the cord, thus distinguishing the paralysis which ensues from that resulting from disease of the brain or white columns.

17. The electrical reactions in loss of motion from disease of the grey matter of the cord, although the same in kind, is distinguished from peripheral paralysis, by the difference of its distribution.

18. In paralysis from degeneration of the anterior cornua of the cord, the abnormal electrical reactions may be distributed in three ways:—*a.* They may extend universally throughout a limb, which indicates that the disease of the centre is *en masse.* *b.* They may be confined to certain groups of muscles which act in physiological concert, irrespective of nerve supply, pointing to chronic degeneration of the multipolar cells; and *c.* They may attack the muscles in an irregular manner, which is usually associated with an acute inflammatory invasion.

19. Quantitative and qualitative changes also occur in lesions of a peripheral nerve. These are to be distinguished from those associated with disease of the anterior cornua of the cord, by the fact of their being confined to the nerve and the muscles it supplies. The distribution of the paralysis is therefore anatomical, rather than physiological.

20. In disease of the anterior cornua, the electrical reactions may present three forms. *a.* The nerve only is degenerated. *b.* The muscle only is altered; and *c.* Both nerve and muscle are changed. Each of these show different clinical features, and constitute a different disorder.

21. In peripheral paralysis, the extent, degree, and character of the electrical reactions to nerve and muscle, give exact indication of their histological condition.

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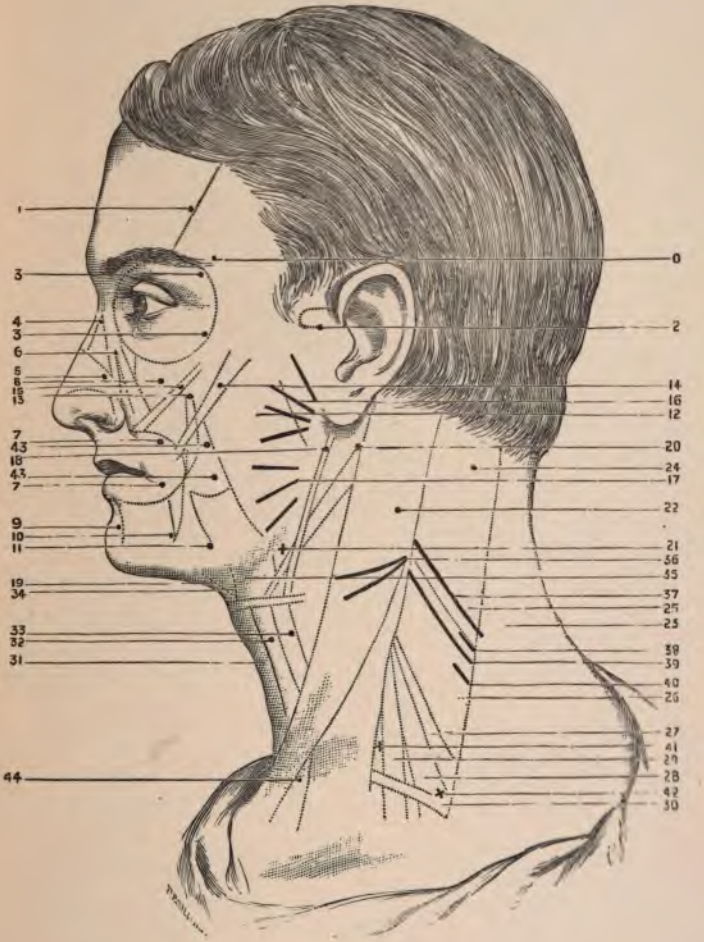
DESCRIPTION OF PLATE I.

SUPERFICIAL MUSCLES AND NERVES OF THE HEAD AND NECK.

0. Motor point of Corrugator Supercilii muscle.
1. Motor point of Frontalis muscle.
2. Motor point of Anterior Auricular muscle.
3. Motor points of Orbicularis Palpebrarum muscle.
4. Motor point of Pyramidalis Nasi muscle.
5. Motor point of Triangularis Nasi muscle.
6. Motor point of Levator Labii Superioris Alæque Nasi muscle.
7. Motor points of Orbicularis Oris muscle.
8. Motor point of Levator Labii Superioris muscle.
9. Motor point of Levator Menti muscle.
10. Motor point of Depressor Labii Inferioris muscle.
11. Motor point of Depressor Anguli Oris muscle.
12 Masseter muscle.
13. Motor point of Levator Anguli Oris muscle.
14. Motor point of Zygomaticus Major muscle.
15. Motor point of Zygomaticus Minor muscle.
16. Nerve Trunks of Tempero-facial nerve.
17. Nerve Trunks of Cervico-facial nerve.
18. Motor point of Stylo-hyoid muscle.
19. Anterior belly of Digastric muscle.
20. Motor point of posterior belly of Digastric muscle.
21. Trunk of Hypoglossal nerve.
22. Motor point of Sterno-mastoid muscle.
23. Trapezius muscle.
24. Motor point of Splenius Capitis muscle.
25. Splenius Colli muscle.
26. Levator Anguli Scapulæ muscle.
27. Posterior Scalenus muscle.
28. Middle Scalenus muscle.
29. Anterior Scalenus muscle.
30. Posterior belly of Omo-hyoid muscle.
31. Sterno-hyoid muscle.
32. Motor point of anterior belly of Omo-hyoid muscle.
33. Motor point of Thyro-hyoid muscle.
34. Mylo-hyoid muscle.
35. Hyo-glossus muscle.
36. Trunk of Superficial Cervical nerve.
37. Trunk of external branch of Spinal Accessory nerve.
38. Trunk of branch to Rhomboid and Serratus muscles.
39. Trunk of branch to Levator Anguli Scapulæ muscle.
40. Trunk of branch to Supra- and Infra-spinatus muscles.
41. Trunk of Phrenic nerve.
42. Trunks of Cervical Plexus.
43. Motor points of Buccinator muscle.
44. Motor point of Sterno-hyoid muscle.

PLATE I.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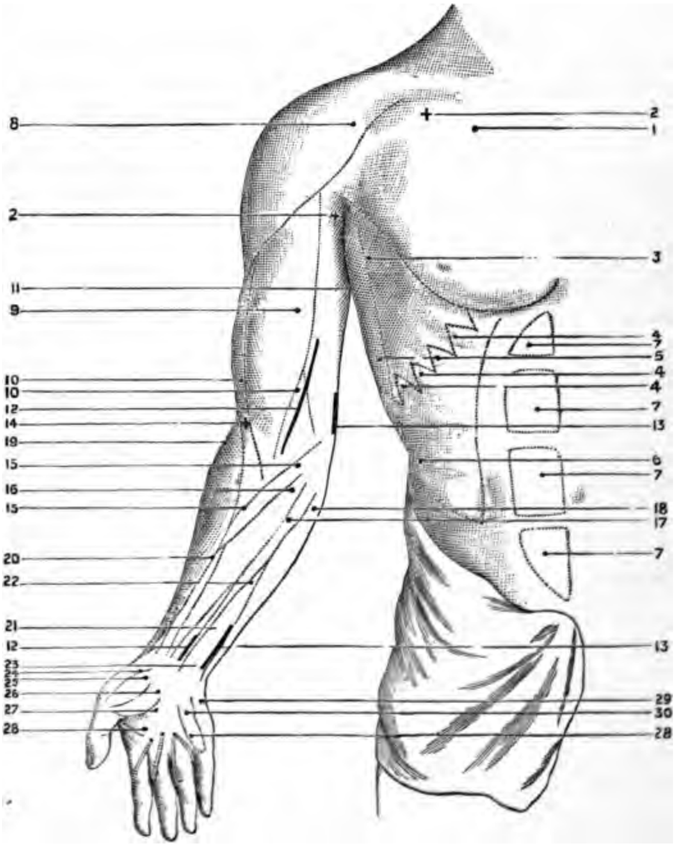
DESCRIPTION OF PLATE II.

SUPERFICIAL MUSCLES AND NERVES OF THE ANTERIOR ASPECT OF THE TRUNK AND UPPER EXTREMITY.

1. Motor point of Pectoralis Major muscle.
2. Brachial Plexus.
3. Motor point of Serratus Magnus muscle.
4. Motor points of External Oblique muscle.
5. Motor point of Latissimus Dorsi muscle.
6. Motor point of Internal Abdominal Oblique muscle.
7. Motor points of Rectus Abdominis muscle.
8. Motor point of Deltoid muscle.
9. Motor point of Biceps muscle.
10. Motor points of Brachialis Anticus muscle.
11. Triceps muscle.
12. Trunk of Median nerve.
13. Trunk of Ulnar nerve.
14. Trunk of musculo-spiral nerve.
15. Motor points of Pronator Radii Teres muscle.
16. Motor point of Flexor Carpi Radialis muscle.
17. Motor point of Palmaris Longus muscle.
18. Motor point of Flexor Carpi Ulnaris muscle.
19. Motor point of Supinator Longus muscle.
20. Motor point of Flexor Sublimis Digitorum muscle.
21. Flexor Sublimis Digitorum muscle.
22. Motor point of Flexor Longus Pollicis muscle.
23. Flexor Profundus Digitorum muscle.
24. Motor point of Abductor Pollicis muscle.
25. Motor point of Opponens Pollicis muscle.
26. Motor point of Flexor Brevis Pollicis muscle.
27. Motor point of Adductor Pollicis muscle.
28. Motor points of Lumbricales muscles.
29. Motor point of Abductor Minimi Digiti muscle.
30. Motor point of Flexor Brevis Minimi Digiti muscle.

PLATE II.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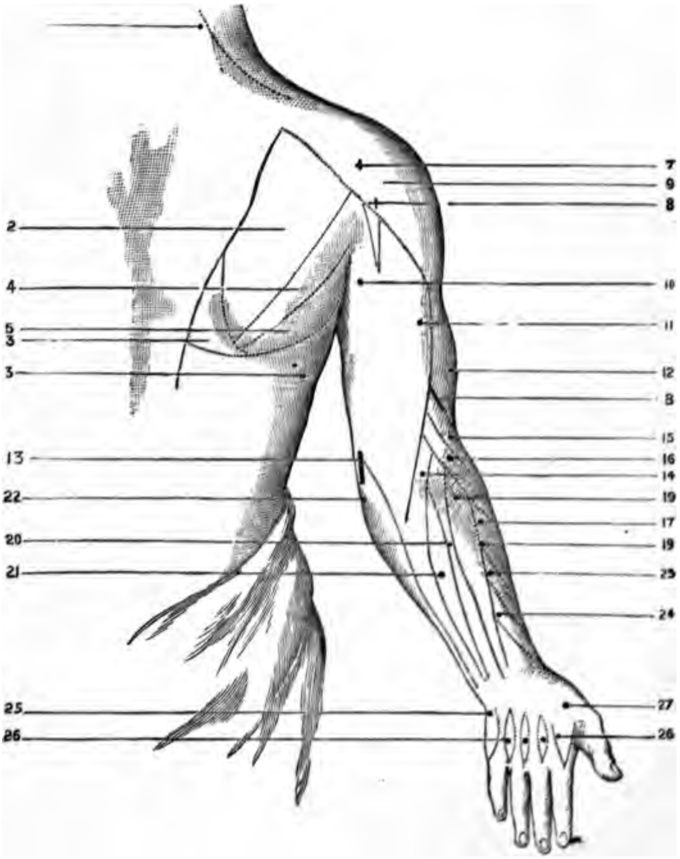
DESCRIPTION OF PLATE III.

SUPERFICIAL MUSCLES AND NERVES OF THE POSTERIOR ASPECT OF THE TRUNK AND UPPER EXTREMITY.

1. Motor point of Trapezius muscle.
2. Infra-spinatus muscle.
3. Rhomboid Major muscle.
4. Teres Minor muscle.
5. Teres Major muscle.
6. Motor point of Latissimus Dorsi muscle.
7. Trunk of Circumflex nerve.
8. Trunk of Musculo-spiral nerve.
9. Deltoid muscle.
10. Motor point of long head of Triceps muscle.
11. Motor point of external head of Triceps muscle.
12. Motor point of Brachialis Anticus muscle.
13. Trunk of Ulnar nerve.
14. Motor point of Anconeus muscle.
15. Motor point of Supinator Longus muscle.
16. Motor point of Extensor Carpi Radialis Longior muscle.
17. Motor point of Extensor Carpi Radial Brevior muscle.
18. Motor point of Extensor Communis Digitorum muscle.
19. Motor point of Extensor Indicis muscle.
20. Motor point of Extensor Minimi Digiti muscle.
21. Motor point of Extensor Carpi Ulnaris muscle.
22. Motor point of Flexor Carpi Ulnaris muscle.
23. Motor point of Extensor Ossis Metacarpi Pollicis muscle.
24. Motor point of Extensor Primi Internodii Pollicis muscle.
25. Motor point of Abductor Minimi Digiti.
26. Motor points of External Interrossei muscles.
27. Motor point of Adductor Pollicis.

PLATE III.

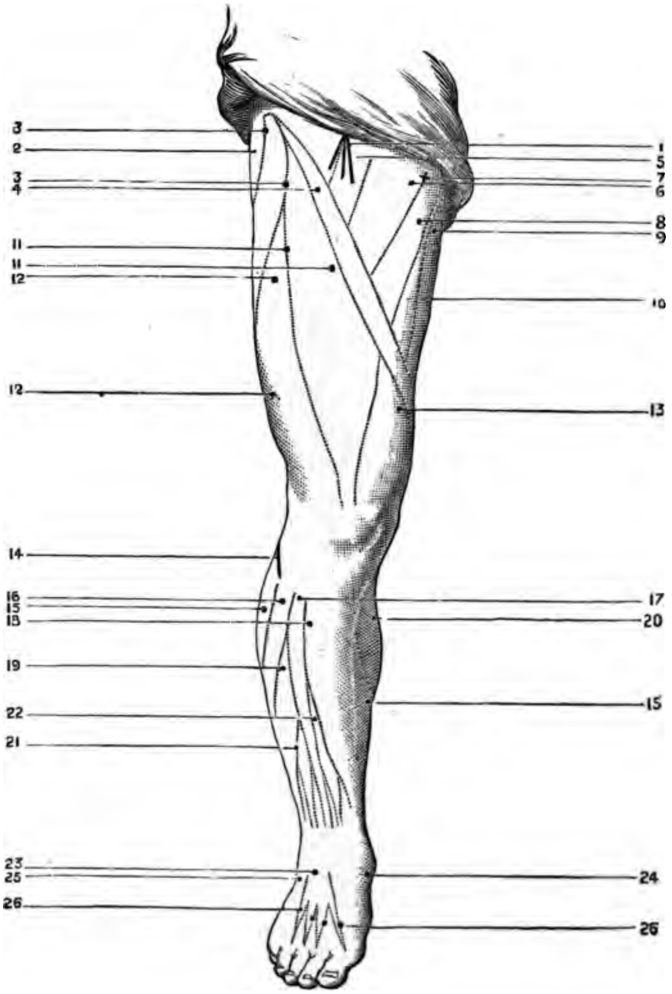


DESCRIPTION OF PLATE IV.

SUPERFICIAL MUSCLES AND NERVES OF THE ANTERIOR ASPECT OF THE LOWER EXTREMITY.

1. Trunk of Anterior Crural Nerve.
2. Gluteus Medius muscle.
3. Motor points of Tensor Vaginæ Femoris muscle.
4. Motor point of Sartorius muscle.
5. Psoas and Iliacus muscles.
6. Motor point of Pectineus muscle.
7. Trunk of Obturator nerve.
8. Motor point of Adductor Longus muscle.
9. Motor point of Gracilis muscle.
10. Adductor Magnus muscle.
11. Motor points of Rectus Femoris muscle.
12. Motor points of Vastus Externus muscle.
13. Motor point of Vastus Internus muscle.
14. Trunk of Peroneal nerve.
15. Motor points of Soleus muscle.
16. Motor point of Peroneus Longus muscle.
17. Motor point of Extensor Longus Digitorum muscles.
18, Motor point of Tibialis Anticus muscle.
19. Motor point of Peroneus Brevis muscle.
20. Motor point of Gastrocnemius muscle.
21. Motor point of Peroneus Tertius muscle.
22. Motor point of Extensor Longus Pollicis muscle.
23. Motor point of Extensor Brevis Digitorum muscle.
24. Motor point of Abductor Pollicis muscle.
25. Motor point of Abductor Minimi Digiti muscle.
26. Motor points of external Interossei muscles.

PLATE IV.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DESCRIPTION OF PLATE V.

Superficial Muscles and Nerves of the Posterior Aspect of the Lower Extremity.

1. Gluteus Medius muscle.
2. Motor point of Tensor Vaginæ Femoris muscle.
3. Gluteus Maximus muscle.
4. Trunk of Great Sciatic nerve.
5. Motor point of Vastus Externus muscle.
6. Motor points of short head of Biceps muscle.
7. Motor point of long head of Biceps muscle.
8. Motor point of Semitendinosus muscle.
9. Motor point of Semimembranosus muscle.
10. Motor point of Adductor magnus.
11. Gracilis muscle.
12. Sartorius muscle.
13. Trunk of Internal Popliteal nerve.
14. Trunk of External Popliteal nerve.
15. Motor points of Gastrocnemius muscle.
16. Motor points of Soleus muscle.
17. Flexor Longus Digitorum muscle.
18. Trunk of Posterior Tibial nerve.
19. Peroneus Longus muscle.
20. Peroneus Brevis muscle.

PLATE V.